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PROPERTIES AND CLASSIFICATION OF THE PAHA LOESS-DERIVED SOILS IN NORTHEASTERN IOWA[1]

Wayne H. Scholtes[2]

INTRODUCTION

It has long been recognized by geologists that local deep accumulations of loess oriented in a northwest-southeast direction occur on the northeast Iowan drift plain. Earlier investigators reported that these accumulations of loess, called paha (27), are present in many counties in northeast Iowa.

The soils derived from loess on the paha were originally mapped as members of the Clinton, Fayette, and Tama series. Preliminary observations in the field indicated that the soils on the paha should perhaps not be classified with the soils of the Clinton, Fayette, or Tama series.

Studies by Hutton (20) and Ulrich (66) in southwest Iowa, Hunter (19) in southeast Iowa, and Smith (47) in Illinois show that soils derived from one source of loess tend to have characteristics peculiar to that particular loess, its thickness and distribution pattern.

Ulrich (66) concluded for Weisenboden and Planosols in Southwestern Iowa that as the loess thinned the volume weight increased, porosity and permeability decreased, and the degree of horizon differentiation increased. Hutton (20) studying the relationship of loess distribution and soil formation in southwestern Iowa to the morphology of the soil profile found that thickness of loess was related to physical and chemical properties of certain Brunizem (formerly called Prairie) soils. Changes in Brunizem soils in southeastern Iowa developed from thinning loess were attributed by Hunter (19) to time of weathering and variations in parent material. From the studies of these investigators certain morphological, physical, and chemical characteristics were found for established soil series and a clearer understanding was obtained of the genesis of the soils. The soils on the paha may be evaluated and compared to soils which have already been studied through the use of similar techniques of investigation.

The studies reported herein were undertaken to clarify the classification of the soils on the paha. It is hoped that this study will reveal whether new series should be established for these soils on the paha, or whether they should be included with soil series already established in Iowa or elsewhere. It is also hoped that a better understanding will be obtained of the paha in general and of the morphology, genesis and characteristics of the soils which occur upon them.

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HISTORICAL

Classification of Soils on the Paha of the Northeast Iowan Drift Plain

Field and laboratory investigations in recent years have provided information concerning the physical and chemical properties of soils. On the basis of additional physical and chemical information now available, many revisions have been made of soil series established in earlier surveys. The soils on paha were occasionally designated as being different than the Tama, Clinton, or Fayette series. Before the Tama series was established, some of the soils on the paha developed under grass vegetation were designated as Muscatine silt loam (51). In some instances the soils on the paha were mapped as Carrington silt loam or Shelby silt loam. Perhaps the presence of coarse sand grains which occasionally occur within the soil led some of the earlier surveyors to classify these soils with soils derived from glacial drift. However, in the majority of instances the soils of those paha which are recognizable on the soil survey maps are included in the Tama, Clinton, or Fayette series. A brief review of the concepts of soils which have been mapped on the paha of northeast Iowa follows:

Tama series

In 1917, the Tama series was established in Blackhawk County, Iowa, and subsequently has been mapped in Iowa, Illinois, Minnesota, Missouri, Nebraska, and Wisconsin (67).

As described by Stevenson and Brown (52) the Tama series in northeast Iowa was developed from loess under the influence of an annual rainfall of about 35 inches, a prairie vegetation, primarily bluestem (67), and on undulating to rolling topography with good drainage. The surface soil was described as being a dark brown to black silt loam about 10 to 12 inches thick which graded into a lighter brown friable silty clay loam.

Riecken and Smith (36) presently designate the Tama series in Iowa as being somewhat more restricted in several profile properties and geographic range as compared to the range given by Brown. They define the Tama soils as being developed from loess under a paririe vegetation on rounded ridgetops and slopes which range from about 2 to 15 per cent. The surface soil is dark brown to a depth of 9 to 14 inches with a yellowish brown, friable silty clay loam and moderately permeable B horizon. For the Tama series the B horizon ranges from about 28 per cent 2 micron clay in some profiles to as much as 35 per cent in others. Mottlings due to soil-forming processes are not found in the solum. According to the definition of the Tama series by Brown (11), the Tama series was also mapped in counties such as Adair and Washington, but Riecken and Smith (36) have included the Tama of these counties within the range of the Sharpsburg and Otley series, respectively. As defined by Riecken and Smith, the Tama series in Iowa would be expected to occur principally or almost exclusively in the Tama-Downs and Tama-Muscatine soil association areas as shown in Fig. 1.

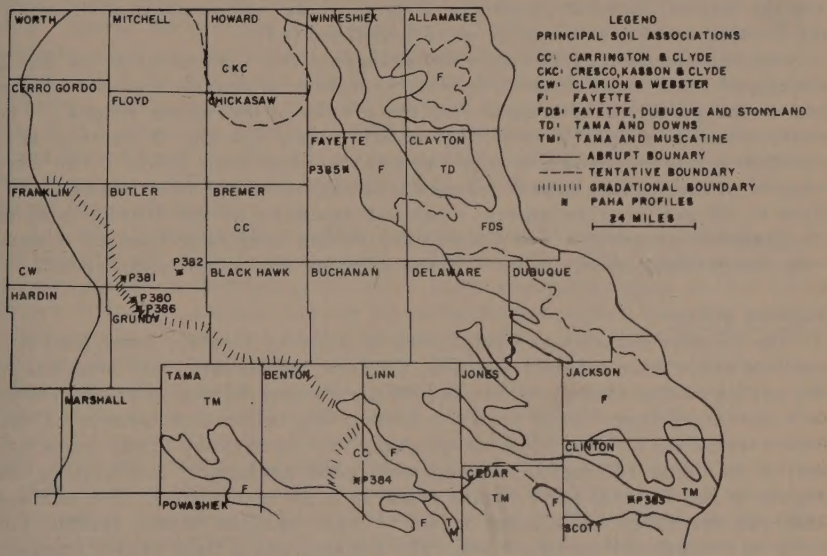

Fig. 1. Location of soil profiles sampled on paha in northeastern Iowa and principal soil association areas of Iowa.

Clinton series

The Clinton series was established in 1916 in Ringgold County, Iowa, and has been mapped in extensive areas in Wisconsin, Minnesota, Illinois, Iowa, and Missouri (67).

As described by Stevenson and Brown (55) the Clinton series in northeastern Iowa was developed from loess under the influence of an annual rainfall of about 30 to 37 inches and under a forest vegetation, consisting primarily of white and red oak, hickory, elm, walnut, basswood, and hard maple, on gently to sharply rolling topography with good drainage. The surface soil was described as being a light grayish-brown or dull gray, slightly compact silt loam about 8 to 10 inches thick which graded into a light brown to buff colored silt loam subsoil.

Originally the Clinton soils were defined as having a distinct set of characteristics differing from those of the Fayette soils. However, both soils were widely recognized and mapped, eventually losing their original identity in northeastern Iowa. Field and laboratory studies in recent years have shown that the name Fayette was used in some counties for soils which were called Clinton in other counties. At other times the Clinton name was applied to soils having a silty clay loam or silty clay B horizon, while the name Fayette was reserved for soils with a heavy silt loam or light clay loam B horizon. The characteristics of the Fayette and Clinton soils with respect to parent material, climate and degree of illuviation were also poorly defined.

Due to the confusion concerning the correlation of Clinton and Fayette soils, a cooperative field and laboratory study of the loess-derived soils of the upper Mississippi Valley was inaugurated between several states

and the United States Department of Agriculture. As a result of the study the Clinton and Fayette series were redefined (69).

Riecken and Smith (36) currently designate the Clinton soils as being developed from loess under a forest vegetation on narrow rounded ridges and on the gentler slopes bordering the breaks of the broad ridges. The surface soil is a light brownish gray silt loam, and the B horizon is a mottled yellowish brown slowly permeable silty clay loam. The clay content of the Clinton subsoil ranges from about 35 per cent in some profiles to 40 per cent in others. Natural drainage of the Clinton soil is adequate for cropping. The Clinton series has been redefined as occurring almost exclusively in the Clinton-Lindley soil association areas.

Fayette series

The Fayette series was established in Fayette County, Iowa, in 1919, and has since been mapped in Iowa, Illinois, Minnesota, and Wisconsin. According to Stevenson and Brown (59) the Fayette series in eastern Iowa was developed from loess under a forest vegetation comparable to that under which the Clinton soils developed. The topography of the soils was stated as being rolling or sloping with good drainage. Rainfall in the region of the Fayette soils varies from 32 to 36 inches (68). The surface soil was described as a light brown to light grayish brown friable silt loam to a depth of 8 to 10 inches. The subsoil was a light brown compact friable silt loam which graded into a lighter colored silt loam at a depth of 18 to 20 inches.

Riecken and Smith (36) presently designate the Fayette soils as being developed from loess under a forest vegetation on ridgetops and adjacent slopes varying from 2 to 20 per cent. The surface is a light brownish gray silt loam 4 to 6 inches in depth. The B horizon is a yellowish brown light slity clay loam which ranges from about 28 to 35 per cent clay. The Fayette series has been restricted more or less in Iowa to the Fayette, and Fayette, Dubuque, Stonyland soil association areas as shown in Fig.1.

Formation of Soils on the Paha

The paha considered in this study are located on the Iowan drift plain of northeastern Iowa. Throughout their range of distribution on the drift plain the climate is rather uniform with an average annual precipitation of about 30 to 36 inches (68). Seasonal temperatures show only slight differences between the extremities of the area. The greatest difference in average frost-free period between the north and south parts of the area is a matter of only 15 days. Climate, therefore, is not an important cause of differences among the soils of the paha. As the soils of the adjacent Iowan glacial drift plain occur in the same area as the paha, no differences would be expected between soils of the paha and the drift-derived soils due to climate.

Time can be considered unimportant in causing differences between the soils of the paha as the paha are of the same age. Then, too, the soils of the adjacent drift plain are approximately the same age as the paha and, consequently, time should cause little or no difference between the drift-derived soils and the soils of the paha.

Topography might be expected to cause minor differences between the

soils on the paha. The paha have rather steep slopes and narrow ridgetops. Local differences in slopes undoubtedly cause some differences between soils on the paha. In general, the slopes of the soils on the Iowan drift plain are more gentle than the slopes of the soils of the paha. However, the topography of some areas of Iowan drift is quite similar to that of the paha. As similar slopes in the Iowan drift area and the paha areas do not have similar soils, topography can be considered unimportant in causing differences between soils of the paha and soils of the adjacent Iowan drift plain.

The effect of vegetation, other factors being similar, is evidenced in the morphology of soils on the paha. Those soils on the paha which developed under a vegetation of trees have characteristics of the Gray Brown Podzolic soils, whereas those developed under a grass vegetation have characteristics of the Brunizem soils. The soils on the Iowan drift plain adjacent to the paha were derived under a grass vegetation. Many soils on the paha were also derived under a grass vegetation, yet differ from soils derived from Iowan drift. Therefore, differences due to vegetation between these soils and soils on the paha would be caused only when the soils on the paha were derived under a vegetation of trees.

The loess of the paha does not appear to be as homogeneous as loess from other sources. Thus, differences in parent material of the paha could result in the formation of different soils on any one paha or between paha. The loess parent material of the soils on the paha, although somewhat heterogeneous, is considerably more uniform than the glacial till parent material of soils adjacent to the paha. Parent material, then, is thought to be important also in causing differences between the soils of the paha and the soils of the Iowan drift plain.

An understanding of the parent material of the soils on the paha is necessary to explain some of the characteristics of the different soils. The factors which affect the parent material of these soils, such as mode of deposition, climate during deposition and time of deposition should be considered in detail. The proper diagnosis of the parent material may help provide a basis for correct evaluation of the place of the soils on the paha in our present system of classification. The sand very infrequently found in small areas on some paha is considered extraneous to this study, because of their infrequent occurrence and lack of appreciable amounts of silt.

Many of the geological references have been cited and discussed by various authors. Unless previous research by such authors has an intimate bearing on the problem, it will only be mentioned.

Mode of Loess Deposition

In 1870 Richtofen first suggested the eolian origin of the loess deposits of China. Todd (63) and his associates objected to this hypothesis and proposed an aqueous origin of the silty material. Shimek (45) studied the problem for more than 50 years and cited his observations to disprove the aqueous concept of Todd. In 1897 Chamberlin (15) supported the eolian theory, but it was a modified fluvio-eolian hypothesis. This mechanism he proposed is currently accepted as responsible for the loess deposits of this region.

Climate During Loess Deposition

Shimek (43, 44, 45) and Baker (7) concluded that the climate during loess deposition was similar to our present climate. Kay and Graham (22) believed the climate during loess deposition was becoming increasingly arid.

Age of Loess Deposits

The term "Peorian" set up by Leverett (26) in 1898 was originally proposed as the interval, represented by weathering, at the top of the Iowan loess in Illinois where the Iowan loess is overlain by Tazwell drift. This term became generally accepted for both the period of deposition and the time of weathering of the loess, Leighton (25) and Kay and Leighton (23). In 1941, Kay and Graham (22) interpreted the Peorian interval as including Iowan loess and weathering until the advent of the Mankato ice. Because the loess of the Iowan drift region did not accumulate in only one period, the term Peorian is not applicable to the composite loess. Therefore, Ruhe (37), has used a modified nomenclature to supplant the term Peorian. The composite loess is designated as Wisconsin loess, and where the glacial substage is recognizable the loess associated with it is termed the substage equivalent.

Lodgement Factors Affecting Loess Depth

In studying loess thickness, Smith (47) points out that the loess depth at any point is the resultant of two sets of forces, those of deposition and those of removal. If the loess were deposited on a bare surface with no vegetation, it could have again been picked up by the wind and redeposited elsewhere. Smith observed in Illinois that areas which may have had little or no vegetation during loess deposition, usually are thinly covered with loess. Shallow lakes recently drained showed the loess to be thinner than on higher ground. Areas covered by fine textured, slowly permeable till generally have thinner loess than adjacent till having a more favorable texture for plant growth. He suggested the loess was thinner in these areas because of the scarcity of vegetation to catch and hold the loess. The shallow lakes were probably covered by ice in the fall when loess deposition is thought to have been most rapid, and loess deposited there could have been picked up and redeposited elsewhere. Hobbs (17) described the collection of loess in the tundra, noting that in areas without vegetation the sediments tended to drift and collect in the lee of objects which broke the force of the wind.

Shimek (41) noted that there were three requirements for loess deposition. These were: a source of supply, a transporting agency, and an anchorage for the dust. He stated the first is to be found in river bars, sand dunes, and also areas bare of vegetation. The transporting agency was the wind. Plants furnished anchorage for the dust. Shimek contended that plants were abundant during loess deposition because of the following: 1. The loess is equal or often thicker on ridge tops, indicating that only anchorage furnished by plants could prevent the loose, soft loess materials from washing away. 2. The uniform thickness of the loess in many places suggests its deposition in the shelter of taller vegetation.

3. Abundant root-marks, mostly iron tubules, in many parts of the loess are proof of an abundant vegetation. 4. The presence of an abundant flora is furnished by the fossil land snails which show not only the presence of an abundant vegetation necessary for food and shelter, but also indicate floral type areas.

In his detailed treatise on the eolian mechanism Bagnold (6) points out that in a physical sense vegetation can be regarded as a special kind of surface roughness. He points out that sand grains do not bounce off vegetation as they do from a hard surface, but rather lodge and accumulate. He states that as long as vegetation is alive, the surface on which it grows cannot ever become fully charged with sand, for vegetation grows higher as sand accumulates around it. As a result, under all wind conditions a grassy or vegetated surface acts as a continuous deposition area.

Shimek (42) considers that any type of vegetation will serve as a place of lodgement. He states that under forest conditions the accumulation of loess would be more uniformly blanket-like, whereas grass vegetation would result in a less uniform mantle.

The Problem of the Paha Loess

The term paha was applied to isolated loess capped knobs and ridges within and on the borders of the Iowan drift by McGee (27). Originally, according to McGee, the Dakota Indians applied the name paha, meaning hill or hills, to these prominences. In describing paha McGee (27, p. 220) refers to them as:

> ....loess capped eminences, sometimes elongated to ridges miles in length, sometimes shortened to elliptical hills.

He also described individual paha (27, p. 397) as an:

> ....elongated swell of soft and graceful contour, standing apart on the plain or else connected with its fellows sometimes in long lines, again in congeries, and locally merging to form broad plateaus.

Composition of the Paha

McGee described the paha as typically consisting of the following materials:

1. Loess
2. Loose sand
3. Drift
4. Indurated rock.

However, it is the observation of Shimek (42) that the loose sand may be missing and that the indurated rock may not be discernible. This was also observed in this study. In most exposures the loose sand was not found underneath the loess cap.

Origin of the Paha Loess

McGee (27) postulated that paha were formed by an aqueo-glacial mechanism whereby canyons in the ice became charged with glacial mud. As the ice melted the mud-filled lakes and crevices remained to form eminences of distinctive composition and structure. Where loess was absent from hills of high elevation McGee assumed that it had been removed by erosion. Shimek (42) contested McGee's theory that the presence of loess was due to melting ice. He found fossil mollusks in the

loess of the paha and identified them as terrestrial species which could not have existed were McGee's theory correct.

Norton (33) considered that the problem of the paha consisted of two parts: the origin of the till nucleus and of similar pahoid hills with no loess, and the origin of the loess cap. Concerning the origin of the loess cap, he attempted to support the fluvio-lacustrine hypothesis of loess formation on the paha advanced by McGee. However, Norton did not subscribe to the portion of McGee's theory regarding the absence of loess from local eminences. He reported that in Linn County some hills which were paha in form had no loess and stated that there was no reason to believe that loess had ever been deposited upon them. Norton (33) objected to Shimek's eolian hypothesis as applied to the loess of the paha. He concluded the aeolian hypothesis did not explain the presence of isolated masses of loess on the paha and its absence from intermediate areas.

Shimek (42) contended, however, that in the light of surface conditions as related to floral development and distribution, this was in reality further substantiation of the eolian theory. The elevations were the first to be drained and to present favorable growth conditions for the development of lodgement vegetation. They also acted as an obstacle which was gradually built up by material blown upward along the surface. The dust would be carried upward where it would lodge in the established vegetation. Shimek also answered Norton's statement (33, p.385) that "it would seem that loess, if of eolian derivation, should be as widespread over the country as the channelless currents of the air which laid it." He pointed out that loess would be deposited only when the three requirements for loess deposition, namely, source, agency, and anchorage were fulfilled. Norton's final objection to loess as eolian in origin, was that if loess had been rapidly deposited in a forest there should have been an accumulation of logs and similar material, and, if slowly deposited, the loess should have been leached free of carbonates. Shimek dismissed the possibility of rapid deposition because as carbonaceous materials occur in only very small amounts in paha loess, decomposition could occur only if deposition were slow. He dismisses Nortons idea that slow deposition was accompanied by decalcification by pointing out the possibility of the return of calcareous material with the dust from the source area. Shimek refuted the fluvio-lacustrine theory of McGee and Norton, and emphasized the importance of the fossil fauna in discrediting this theory.

Bagnold (6) asserts that the detailed shape of the seif dune assumes several different sub-types according to the particular long-period wind regime which prevails in the area. The essential feature common to all dunes is a single continuous ridge which swells and rises at regular intervals to form a chain of summits. That the paha conform to this configuration is illustrated by the definition of the paha given by McGee (27).

In his study of eolian sand deposits Bagnold (6) found that once fine solid particles smaller than 0.03 mm have settled to the ground after being carried by the wind, they cannot be swept up again individually. This is because they sink into a viscid surface layer of air and are out of reach of the disturbing influence of the eddies of turbulence. The ground surface acts as a dust trap. However, the wind can still exert its local pressure on small aggregations of particles which the wind can treat as though they are sand grains. When a wind begins to blow, its first action

is to tear off such projections and redisintegrate them.

Scholtes and Smith (49) using the same line of reasoning as Bagnold have postulated the formation of the paha loess due to movement of sand and sand-sized aggregates of silt and clay by saltation. They point out that in Franklin County a large paha revealed a lack of sorting compared to even the coarse loess in Illinois analyzed by Smith (47). The mechanism of saltation for at least some of the loess material on the paha might account for the poor sorting and heterogeneity of the soil materials found on the paha. With both sand particles and sand-sized aggregates of silt and clay moving by saltation, formation of longitudinal dunes would be quite possible. Presumably such movement would have occurred before vegetation covered the Iowan drift plain and was concurrent with the formation of the ventifacts in the Iowan pebble band. Such conclusions are consistent with other data such as that shown by Moss (28). He analyzed a number of soil drifts which were moved from bare fields. His data showed that the drifts, which behave like sand drifts, vary but little in texture from the soil in the fields from which they blew. While some silt and clay are completely removed from the area by the dust storms, the drifts which are formed are only slightly coarser than the original material.

Orientation of the Paha

McGee (27) pointed out that one of the most striking characteristics of the paha was their consistent general orientation. The paha all have a west-east to northwest-southeast orientation. He noted that in the northern part of the Iowan drift plain the longitudinal axis of the paha had a N 45° to 50° W. In the east central portion of the drift plain their longitudinal orientation was N 50° to 60° W. In the southwest part of the Iowan drift plain the paha are oriented about N 45° w. The main axes of the paha become oriented more westerly proceeding to the southeast so that in Scott County they are aligned almost exactly westward.

Distribution of the Paha

Norton (31, 31, 32, 33), Alden (2), Savage (38), and Calvin (12, 13, 14) recognized the presence of paha within their areas of investigation and reported them in some detail. Other investigators working within the Iowan drift area were cognizant that paha were to be found in the particular county in which they worked as Udden (65), Williams (70), Savage (39), and Arey (3, 4), but they devoted little time to the problems of the paha. In some county geological reports paha are shown on the map of the superficial deposits but in other county reports they are either not shown on the map or no map was made of the superficial deposits.

As reported by Kay and Graham (22), the Peorian loess is very thin on the Iowan drift plain. In Benton County, for example, the loess was shown to be 4 feet thick, except along the border of the Iowan drift plain. On the many paha in Benton County the local accumulations of deep loess were either overlooked or an average depth of the loess for the entire landscape may have been given.

Local areas of loess accumulation within the Iowan drift area were also recognized by workers in soil classification in Iowa. Stevenson and Brown (51, 52, 53) noted the existence of paha on the Clinton lobe of the

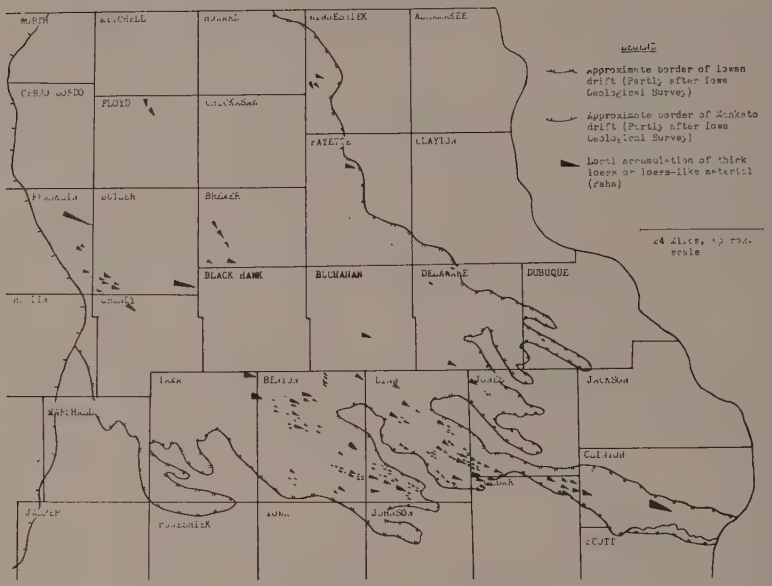

Fig. 2. Location of paha on Iowan drift plain.

Iowan drift in Clinton, Cedar, and Linn Counties. On certain other eastern Iowan county soil maps some paha can be located by soil type pattern, although the presence of paha as such may not have been recognized. On the soil maps of Bremer (50), Fayette (54), Benton (55), Grundy (56), Floyd (57), Winneshiek (58), Delaware (59), Jones (60), and Butler (61), Counties many paha can be located by the soil type pattern. The county soil reports were valuable in helping to determine the location of many paha on the Iowan drift plain as shown in Fig. 2.*

Scholtes and Smith (40) mapped paha which they encountered during the course of field studies and found that paha occurred in most counties in the Iowan drift area in northeast Iowa. Many paha, for example, in Benton County, can be located on the soil map where they are shown as isolated elongated areas of Clinton silt loam. In other counties such as Winneshiek, Linn, and Cedar Counties the soils map shows long isolated areas of loess-derived soils, both forest and prairie-derived, surrounded by soils developed from Iowan drift. Usually these areas are paha. On some soil maps, however, they cannot be located as the classification of soil types used in the mapping did not differentiate the soils of the paha from the surrounding soils. Some county soil maps, as Franklin (46) and Tama (1) Counties, do not indicate clearly the existence of very prominent paha within the county.

*The area shown in Fig. 2 as the Mankato drift border is now recognized as the boundary of the Cary drift (37).

METHODS OF INVESTIGATION

Descriptions of the Area in Which the Paha Occur

The area studied is located in northeastern Iowa. It occupies all or parts of twenty-five counties, and comprises approximately one-fifth the area of the state. It is bounded on the north by the state of Minnesota. The eastern boundary of the Iowan drift area approaches the Mississippi River at distances varying from about 20 to more than 50 miles. The border of the Iowan drift plain becomes very lobate in the southeastern portion where it extends into Clinton County. The area is roughly bounded on the south by the top of the sixth tier of counties south of the Iowa-Minnesota state line. On the west, the Iowan drift plain is bounded by the Bemis moraine of the Cary drift plain. The east, south, and southwest sides of the Iowan drift plain are bordered by thick loess and sand deposits.

Kay and Apfel (21) describe the area as more typically gently rolling than any other portion of the state. They describe the river valleys as being fairly broad in relation to the streams in them, and, instead of the broad valleys having wide flood plains, many of them have concave profiles. They state that the flood plains in some places are not filled with alluvium, but are drift flats appearing about the same today as when the Iowan glacier disappeared.

The broad valleys are fringed by lines of hills which vary in slopes from gentle to steep. The relief is not great in any locality, being usually less than 100 feet. The divides are generally undifferentiated by prominences from the hills which border the stream valleys. The relief is very slight in parts of the drift mantled plain, but it is sufficient to provide surface drainage. No lakes occur on the drift plain, but colluvial areas may become the site of shallow ponds after heavy rains.

The bulk of the Iowan drift is very thinly mantled by poorly sorted loess. A pebble band underlies the poorly sorted material most commonly at depths of from 1 to 2 feet. Riecken and Smith (36) have indicated that well sorted blanket loess occurs on the southwestern portion of the northeast Iowan drift plain. They show an area of well sorted loess of 30-100 inches thickness extending from south central Benton County to the northern portion of Tama County, the southwestern two-thirds of Grundy County and most of Franklin County east of the Cary drift border. Kay and Graham (22) indicate that most of the Iowan drift is overlain by two feet of loess. Their map of the thickness of the Peorian loess shows a great increase in loess thickness around the border of the Iowan drift.

Although, as previously stated, no great differences in elevation exist in any locality on the Iowan drift plain, an eminence of 25 to 75 feet becomes very prominent when surrounded by a very gently undulating plain. The paha become strikingly obvious on the drift plain because of their rise in elevation above the adjacent drift. In addition to their rather abrupt rise from the drift plain, their billowy configuration coupled with their very similar orientation makes them conspicuous. Different soils are likely to occur on the paha than on the adjoining drift plain because soil forming factors differ. However, prominences on the Iowan drift plain may not always be paha, for some prominences may consist of Iowan

till with little or no loess present. In other cases the pahoid prominences may be thin loess covered inliers of Kansan drift within the Iowan drift area.

Field Studies

Location of Paha on Northeast Iowan Drift Plain

It has already been noted that early workers in geology and soils have recognized that paha exist in many counties on the Iowan drift plain. However, there has been no special effort made to map their occurrence and extent in detail. From a soil genesis and classification viewpoint, before investigating the characteristics of soils occurring on the paha, it was considered that information was needed on the number, distribution and extent of the paha in northeast Iowa. Such information would permit better selection of profiles as well as sites which could be studied in moderate detail.

There seems to have been some confusion among some of the earlier workers regarding the character of the paha. Shimek (42) points out, for example, that some of the areas referred to as paha south of Waverly were misnamed. An unmantled area of Kansas inlier had been misinterpreted as Iowan and some of the Kansan ridges within the area that are thinly covered with loess were erroneously referred to as paha.

For purposes of this study the paha are defined as Wisconsin loess capped prominences with pre-Iowan nuclei, oriented in a west-east to northwest-southeast direction, occurring either within the Iowan drift plain or along its border, and partially or completely surrounded by Iowan till. The term Wisconsin (37) is applied to the loess of the paha, because no stratigraphic divisions are found within the loess. The paha may contain loess increments deposited during all of the Wisconsin age, but it is thought to consist primarily of Iowan loess.

After the study was undertaken in 1948, an effort was made to record the location of all paha encountered in the field. Scholtes and Smith (40) compiled a map showing the distribution of paha they had encountered through 1949. Fig. 2 illustrates the current map through 1954. Only those paha actually encountered in the field studies have been shown on the map.

It is apparent from Fig. 2 that there are considerable numbers of paha scattered over the Iowan drift plain. They are much more numerous in the southern portion of the area than further north. On the basis of the paha so far encountered it appears that Benton, Linn, and Jones Counties contain the bulk of the paha. However, future detailed investigation will probably reveal many additional paha.

To determine if there were many paha in any county, it was decided to make a detailed road traverse of two. Paha were identified in the field to make certain that high hills of till would not be mistaken for paha. Accordingly, Benton and Linn Counties were arbitrarily selected for a detailed traverse to determine the number of paha in the counties. Scholtes and Smith (40) showed a total of seven paha in Benton County in 1949.

The soils maps of Benton and Linn Counties were examined for isolated and elongated soil type areas showing a northwest-southeast orientation.

Aerial photos* for these areas were studied to determine the possible location of paha. From field studies it soon became evident that there were many additional paha which could not be located from information on the soils map. Consequently, it was decided that a traverse of most roads should be made to locate all paha and to sketch their boundaries on aerial photos as they were observed in the field. Between 800 and 1000 miles of road were traversed in Benton and Linn Counties to plot the location of paha. As the paha occupy prominent positions on the landscape they were observable from considerable distances, usually 1 to 2 or more miles. Consequently, it was not necessary to drive each and every road in the county.

After working with aerial photographs it became evident that paha are often indicated on photos by the general appearance of the pattern of the landscape. Clues as to the presence of paha may be obtained from aerial photos by conspicuous topographical features, erosional differences and the presence of forested areas. Paha are often evident from aerial photos by their distinct form and topography. The use of overlapping photographs to permit usage of a steroscope is a further aid in recognizing paha of topographical differences.

The soils of the paha are usually more erosive than the adjacent soils, due to their steeper slopes and lower clay and organic matter content. As a result, paha are often evident from the aerial photo by the lightness of the color pattern on the photo. Once erosion has removed most of the surface soil on a paha, the eroded area shows on the photograph as a light area with characteristic paha orientation. In some instances gully erosion may also give a clue as to the presence of paha by the large number of short deep gullies which are found on the sides of the paha. Many of the paha were originally covered by forest vegetation. Where the trees have not been removed, they often indicate paha areas. The trees follow the general configuration of the paha and consequently outline the boundaries of the paha from the surrounding area on the aerial photographs.

After each paha was delineated on the aerial photograph it was transferred to the detailed county road map. Forty-seven paha were found in Benton County, and sixty in Linn County (Fig. 3). It is not claimed that all of the paha in the two counties have been found and plotted, but it is believed that the bulk of them have been located. The area around the border of the Iowan drift might reveal additional paha, but this would necessitate detailed field work beyond the scope of this study. However, the number of paha mapped in Benton and Linn Counties with a detailed traverse, if representative of some other counties, would indicate a large number of paha in the state.

Cross Section of Paha

To compare the thickness of loess on a paha to that on the surrounding Iowan drift plain, a cross section of a paha was made. A paha in northwest Grundy County was selected because it was isolated on the Iowan drift plain. This paha was considered to be a typical paha as to configu-

* The Benton County Soil Conservation District Office at Vinton loaned aerial photos and provided office facilities for this phase of the study. This assistance is gratefully acknowledged.

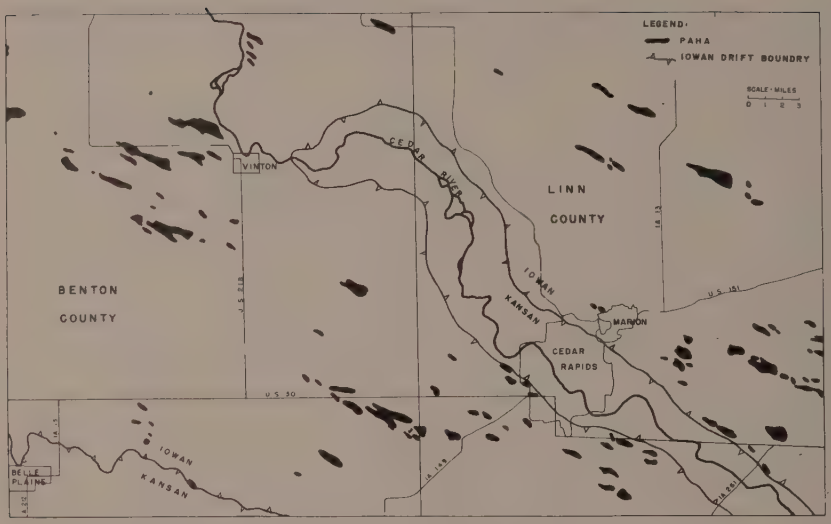

Fig. 3. Distribution of paha in Benton and Linn Counties

ration and orientation. Also it was considered that a traverse of deep borings bisecting the paha perpendicular to its main axis would provide information as to the nature of the material underlying the loess and the nucleus of the paha.

Accordingly, after the paha in Grundy County was selected the writer with the assistance of Dr. Guy D. Smith made a traverse* of deep borings across the paha. The initial point was placed on the high point of the paha, designated as the bench mark, and the traverse extended along a north-south road a distance of 700 feet north and 1500 feet south of the starting point. The paha was bisected at its lee or southeastern end by the traverse which extended to the level of the drift plain on the north end to the local high point of the drift plain on the south. Surface elevations were obtained at each boring site by using a level and elevation rod, and horizontal distances were measured with a 100 foot steel engineering tape. At each boring site information was obtained regarding the surface elevation, the thickness of the loess and/or total eolian mantle, including sands and silts, and the nature of the materials underlying the loess. The results are shown in Fig. 4. In addition to the above information, the depth to carbonates was also recorded for each boring site. A log was kept of each boring and interpretations of a soils and geological nature were made.

The core or nucleus of the paha consists of strongly weathered till, or gumbotil, interpreted to be Kansan in age. This has been observed to be the case, too, for almost all the other paha investigated to date. The high point of the Kansan inlier is about fifteen feet above the high point of the

*Traverse located along west edge of SW $\frac{1}{4}$ Section 7, T 89N, R 17W.

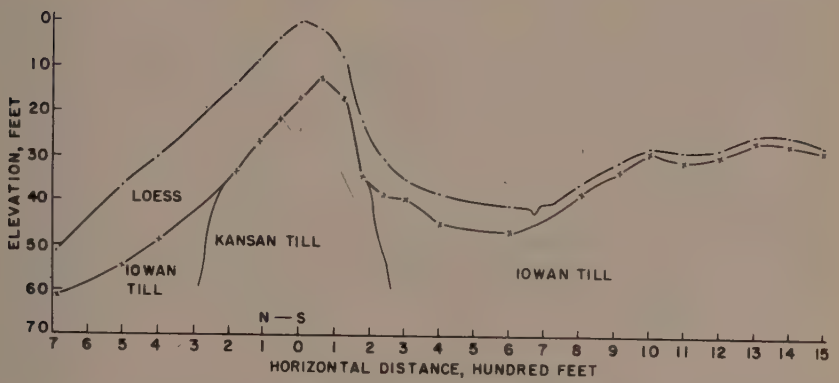

Fig. 4. Cross section of paha and adjacent area in Grundy County, showing elevation, thickness of loess, and character of pre-loess topography.

adjacent Iowan drift on the traverse. The ground surface at the high point on the traverse is about 23 feet higher than the adjacent local high on the Iowan drift plain to the south and more than 50 feet higher than the surface of the plain to the north. The Kansan inlier may be somewhat higher in the northwest part of the paha. At the site of soil profile P-380 the ground surface is higher and the loess was found to be 25 feet deep. The deep loess mantle is not coextensive with the Kansan drift nucleus in this paha, but is larger. In the southeast end of the paha, the loess streams out onto the Iowan drift and no Kansan is visible in a road cut across the end of the paha.

The cross section of this paha reveals that the loess is thickest on the north side or windward side. However, this does not hold true for all paha, and the writer has observed that most of the paha have the loess thickest on the lee side.

Morphological Studies and Collection of Soil Profile Samples

At present there is one major soil association, the Carrington-Clyde, recognized on the Iowan drift plain (36). The soils which occur on the paha have not been designated on the soil association map due to the small areal extent of the paha. Riecken and Smith (36), however, have indicated the location of some local accumulations of thick Peorian loess which possibly include paha in the area of Iowan drift in northeast Iowa.

In order to study the soils which occur on the paha, profile sites were selected which represented the geographic distribution of the paha. Sites were selected near the western edge of the northeast Iowan drift plain (P 385), in Grundy County (P 380, P 386) and in Butler County (P 381, P 382); near the southern border in Benton County (P 384); near the southeast border in Clinton County (P 383); and near the northeast part in Fayette County (P 385). The sampling sites selected were on the gently rounded shoulders of the paha with about 3 to 6 per cent slopes. The profile samples were taken from pits dug in fields which were cultivated or in pasture or from freshly exposed roadside ditch banks.

All profiles selected were naturally well drained internally and externally and included soils developed under prairie, forest, and prairie-forest vegetation. At each profile site a pit was dug or ditch bank cut back to expose the soil profile in order to collect soil samples and examine the morphology. Detailed descriptions of the seven profiles occurring on paha were made. Color descriptions were made according to Munsell Color Standards. These descriptions are not included here because of their length.

From the morphological descriptions it is evident that the soils developed on the paha do not exhibit any increasing degree of horizon differentiation that could be ascribed to geographic position from a single source of loess, such as is the case of soils in southwestern Iowa developed from loess.

The soil profiles, P-380, P-383, P-385, and P-386 were developed under a prairie vegetation. Profile P-384 showed some evidence of being very recently vegetated by trees. Profile P-381 contained morphological evidence of having been developed under a forest vegetation for a longer period of time. It resembles the soils of the Downs series (1). On the basis of present classification it would be designated as a prairie-forest intergrade soil. Profile P-382 is a Gray-Brown Podzol and undoubtedly developed under the influence of forest vegetation. It has the same general morphology as the Fayette series (36).

From morphological studies it is evident that the soils sampled do not have well developed profiles with the strong horizon differentiation that is characteristic of maximal Brunizem soils (48) and Planosols (66). Profiles P-380, P-383, and P-385 have very weakly developed horizons of clay accumulation. According to the suggestions for sub Great Soil Group classes discussed by Thorp and Smith (62) and Smith, Allaway, and Reicken (48), these soils would probably be classified as minimal Brunizem soils. Profile P-381 would probably be classed as a medial Brunizem-Gray Brown Podzol transition or intergrade soil as it has a definite horizon of clay accumulation. Profile P-382 would be considered to be a medial Gray Brown Podzolic soil, and Profile P-384 a medial Brunizem soil. Profile P-386 showed an accumulation of organic matter but a B horizon was not present as the calcareous loess occurred directly below the A horizon. Therefore, it would be classed as a Regosol. The classification of the soil profiles into their respective sub Great Soil Groups can be summarized as follows:

Soil profile	Sub great soil group
P-380, P-383, P-385	Minimal Brunizem
P-381	Medial Brunizem-Gray Brown Podzol Intergrade
P-382	Medial Gray Brown Podzol
P-384	Medial Brunizem
P-386	Regosol

Only three profiles sampled, namely P-381, P-382, and P-384 have an appreciable accumulation of clay in the B horizon. The P-384 profile had the highest content of accumulated clay in the B horizon of any of the profiles studies on the paha, and its texture profile would be comparable to a typical profile of the Tama series (1). Profiles P-381 and P-382 had less well developed textural profiles than profile P-384.

A striking feature of the soils developed on the paha, is their lack of appreciable mottlings. Other than some low contrast mottlings in one or two profiles, the lower horizons of the profiles appear to be quite well oxidized and aerated. Another feature common to the soils studied on the paha is the single grained massive structure of the lower profile horizons. Elongate cavities appeared scattered throughout these and frequently the material contained many fine pin-hole openings.

Morphological Study of Buried Fossil Soils

When considering the mode of formation of the paha, the fossil soils buried beneath the loess on the paha should be considered. A study of the characteristics of these buried fossil soils might throw some light on the relationship of such soils to the overlying loess. Therefore, in several road banks where the buried soil was exposed beneath the loess on the paha a morphological description was made. The description of two of the buried soils is contained in the following section. A buried soil on the Kansas re-entrant in Tama County was first examined to determine the relationship between it and the overlying Peorian loess. The buried soil in the Kansan area was selected in order to obtain a comparison between it and the overlying Peorian loess.

Buried soil No. 1 (a fossil maximal Gray-Brown Podzol), location: north side of road in road cut in SW $\frac{1}{4}$, Sec. 27, T83N, R13W, Tama County.

Depth (inches)	Horizon designation	Horizon morphology
0-3	A_1	Pale brown (10YR 6/3 moist) gritty silt loam: many iron and manganese concretions; weakly developed platy structure.
3-8	A_2	Pale brown (10YR 6/3 moist) silt loam; coarse well developed platy structure.
8-10	B_1	Yellowish brown (10YR 5/4 moist) silt loam; weakly developed sub-angular blocky structure.
10-18	B_2	Yellowish brown (10YR 5/4 moist) heavy clay loam; sub-angular blocky to angular blocky structure.
18+	B_3	Yellowish brown (10YR 5/6 moist) clay loam; sub-angular blocky structure.

Buried soil No. 2 (a fossil maximal Gray-Brown Podzol), location: west side of road in cut in paha in NE $\frac{1}{4}$, Sec. 13, T86N, R13W, Tama County.

Depth (inches)	Horizon designation	Horizon morphology
0-6	A_2	Light yellowish brown (10YR 6/4 moist) silt loam with considerable grit of silicaceous material; splotched with carbonaceous material; weak platy structure.
6-10	B_1	Yellowish brown (10YR 5/4 moist) heavy silt loam to light silty clay loam; weakly developed fine sub-angular blocky structure.
10-18	B_2	Light yellowish brown (10YR 6/4 moist) heavy clay loam; subangular blocky structure.
18+	B_3	Brownish yellow (10YR 6/6 moist) clay loam; fine angular blocky structure

Morphological descriptions were made of other buried soils underneath the loess mantle of the paha, but are omitted here. Briefly, the morphology of the buried soils on the pre-Iowan core of the paha indicated that they ranged from maximal to medial Gray Brown Podzol and some were so heavily weathered as to be classed as Gray Brown Podzol - Red/Yellow Podzol Intergrades. At the contact zone between many of the buried soils and the overlying calcareous loess many pipestems and snail shells occurred.

Elevations of Paha and Iowan Drift

Although it has been noted that the paha are prominent on the Iowan drift plain, there have been no quantitative measurements made of the differences in elevation between the paha and the surrounding Iowan drift plain and/or between the paha and adjacent Iowan highs of pahoid form. Therefore, elevations were determined on selected paha in Benton County and are shown in Fig. 5.

An altimeter was used which designated elevation differences to two feet. At an initial low point adjacent to each paha the altimeter was set at 0 and positive or negative differences in elevation from the initial point or bench mark were recorded. After traverses of a paha were completed the altimeter was checked again at the initial point to determine any changes which might have affected the elevation readings. In general, the agreement in elevation readings at a given point before and after a traverse was made was within four feet. Traverses were made rapidly to minimize errors due to change in atmospheric pressure in the locality.

The greatest difference in elevation between the high point on a paha and the adjacent Iowan drift plain was found to be 120 feet. In most instances the level of the Iowan drift plain was found to be about 50 feet below the high point of the paha. However, in some cases adjacent high

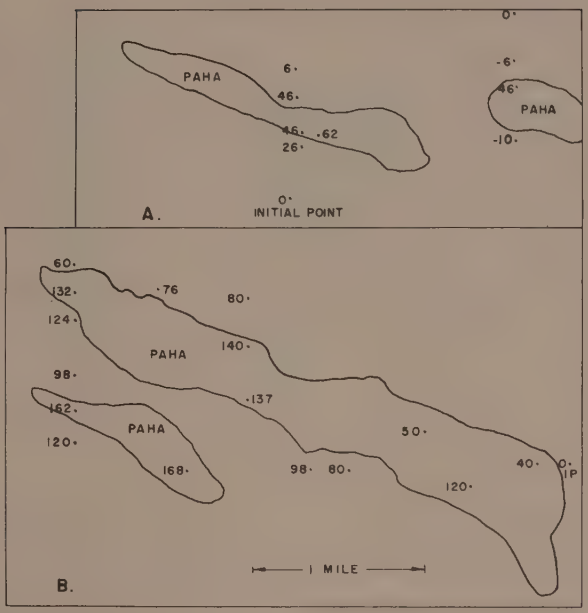

Fig. 5. Two of the road traverses made to determine elevations of paha and of the surrounding Iowa drift.

points on the Iowan drift plain were found to be only a few feet lower than the high point of the paha. In at least one instance an Iowan drift prominence was found to be higher in elevation than portions of the adjoining paha.

Soil Map of a Paha

A soil map was made of a small paha in Benton County to determine the characteristics of the soils in different topographic positions on a paha. The paha selected for mapping is assumed to have been vegetated by prairie, as the morphology of the soil in general was that of modal Brunizem soils. As the soils occurring on the paha have not been classified into series, no attempt was made to classify the soils by series. Rather the soils were classified according to the proposals of Thorp and Smith (62) whereby soils of a Great Soil Group whose characteristics are weakly developed for the group would be considered minimal members of that group or sub-group. Soils whose characteristics are developed beyond the median for the group would be considered maximal. Other members would than be considered medial.

The soils on the paha were classed as to their Great Soil Group and their stage of development. The slope on which they occurred and the thickness of topsoil were also recorded.

The soil map (Fig. 6) shows that all of the soils on this paha could be included in the Brunizem (Prairie) Great Soil Group. No soils encountered

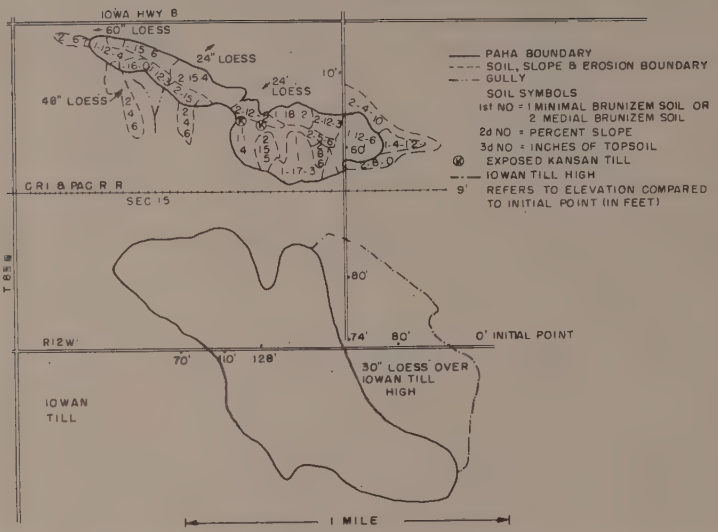

Fig. 6. Detailed soil map of a paha and traverse showing elevation differences between paha and Iowan till plain.

on the paha were well enough developed to be classed as maximal. The soils encountered on the paha were either minimal or medial Brunizem soils. In general, the medial soils resembled morphologically the Marshall or Tama soils (36) and the minimal soils resembled morphologically the Monona soils (36).

The minimal soils were usually found on the paha in the areas with the greatest solar radiation and/or steepest slopes. On the steep slopes geological erosion apparently was sufficiently rapid to keep the profile in a youthful stage. The medial soils usually were found in coves which afforded some protection from solar radiation and hence increased the amount of water available for weathering. Medial soils also tended to occur on more gently sloping areas where erosion was not so severe.

In two places on the paha Kansan till was found at the surface. In one place this till was exposed at the head of a gully. Examination of the soil profile formed from the Kansan till showed that it is a partially truncated profile, that is, the A horizon is very thin and rests directly on what appears to be the B_2 horizon of the fossil till soil. This partial truncation also seems to be true of the other exposures of Kansan till high on the ridge of the paha. It is of interest to note that Smith (47) contends that sites such as these severely eroded soils afforded a poor medium for plant growth, and consequently plant cover was sparse and loess accumulated but thinly. Perhaps the explanation for the Kansan till soil on the paha is that it had been truncated and provided a very poor medium for plant growth and subsequent catchment of the loess. However, geological erosion may have removed loess from these areas at a more rapid rate to expose the fossil till soil at the surface of the paha. Adjacent to the paha the loess varied from less than one foot to more than five feet in thickness in an unpredictable pattern.

LABORATORY STUDIES

Physical Studies

Mechanical analysis. Mechanical analyses were made of the seven soil profiles collected from paha within the area of the Iowan drift plain. The pipette method was used (34). Hydrogen peroxide was used to destroy organic matter with sodium carbonate-sodium hexametaphosphate (64) as the dispersing agent. Sand separations were made by sieving in a reciprocating shaker (24). Fig. 7 gives the results of the mechanical analyses.

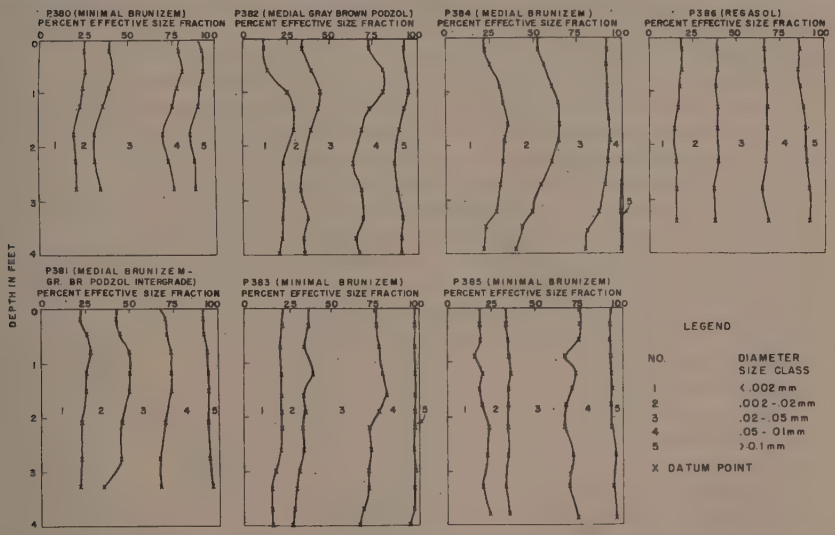

Fig. 7. Distribution of particles by diameter size classes with profile depths of soils on paha.

Four of the seven profiles studies, P-380, P-383, P-385, and P-386, show no accumulation of clay in the B horizon. The data indicate that some clay was formed in the upper horizons and did not move into the lower solum. Even the Regosol, P-386, showed higher amounts of clay in the upper portions if the profile than in the lower portions. However, profile P-385 showed irregular amounts of clay between horizons, which would be difficult to explain on any basis but differences in the material itself as it was deposited.

Profiles P-381, P-382, and P-384 show some concentration of clay in their respective B horizons. Profile P-382 has more clay in the B than the other two profiles. Morphological observations of profile P-382 indicate that considerable horizon differentiation has taken place since the initiation of soil formation. The thin A_1 surface horizon and ashy gray A_2 subsurface horizon are doubtless the result of physical, biological, and chemical changes which have accompanied the movement and/or concentration of clay in the B horizon.

Profile P-384 has about 35 per cent clay in the B horizon as compared to about 27 per cent clay in the B horizon in profile P-382. Yet the clay content of the C horizon of these two profiles is within a few per cent of one another, being about 22 per cent for P-384 and 20 per cent for P-382. Differences in amounts of clay in their parent material would probably not account for the higher clay content of the B horizon in profile P-384 as compared to P-382. It is of interest to note that the fine silt content is higher in profile P-384 than in profile P-382. Therefore, it is possible that clay formation may have proceeded more rapidly in the solum of P-384 than in P-382 because the parent material of the former was finer textured. This was reflected mostly in the content of the silt fraction (18). The distribution of clay with profile depth in the soils on the paha is shown in Fig. 7.

All of the profiles studied contained a considerable amount of sand, especially in the very fine sand size of 50 to 100 microns effective diameter. This is indicative of poor sorting of the material from which the soils on the paha developed. Compared to the loess from which soils in blanket loess areas developed, the soils of the paha contain less silt and more sand. An example of the difference in sand content between loess of the paha and blanket loess is illustrated by the following:

Profile	Horizon	Distance from source	Total sand (per cent)
P-380	C_1	Not known	27.3
P-381	C_1	Not known	33.2
P-382	C_1	Not known	33.8
P-383	C_{ca}	Not known	31.8
15125-27 (47)	C_{ca}	0.6 miles	18.7
15524-28	C_{ca}	1.5 miles	21.5
15515-21	C_{ca}	3.8 miles	0.8
15128-31	C_{ca}	4.5 miles	2.7
15132-35	C_{ca}	9.3 miles	0.0

Mechanical analyses of loess samples by Smith (47) reveal that the loess in Illinois even at distances very close to the source is better sorted than the loess of the paha. For example, the data of Smith show a total silt content of 78.2 per cent at a distance of less than a mile from the floodplain source of the loess. At a distance of 4.5 miles from the floodplain, he found an 89.5 per cent silt content; at a distance of 14.7 miles, 90 per cent silt; and at a distance of 24.2 miles, 90.6 per cent silt. The only appreciable amount of sand he found was 18.7 per cent at 0.6 miles from the source and 21.5 per cent at 1.5 miles from the source. Beyond 4.5 miles from the source he found no sand in the loess. It is of interest to note that Smith's data show the loess in Illinois is well sorted and contains sand only a relatively short distance from the source. The high content of sand in the soils on the paha may indicate that the loess originated very locally. Scholtes and Smith (40) postulated a movement of the paha loess material as sand-sized aggregates of silt, clay, and sand to explain the poor sorting found in soils on the paha. This does not mean, however, that the finer textured material carried into the atmosphere would not also accumulate around the vegetation providing lodgement on the paha.

Volume weight. Volume weight samples of representative horizons were obtained in triplicate at the time the soil profiles were sampled in the field. A steel cylinder with a sharp, tapered cutting edge was inserted vertically into the soil layer to be sampled in a careful manner so that disturbance of the natural soil structure would be kept to a minimum. The cylinder was freed by excavation, the outer surface cleaned, and metal cutters inserted into the slotted sidewalls confining a definite volume of soil.* The samples were reweighed after drying and the volume weight calculated** on an oven dry basis. The data, which represent the averages of the three determinations are presented in Table 1.

An examination of the data in Table 1 reveals an increase in volume weight with depth in most of the profiles. For example, P-384 increases from 1.26 volume weight in the surface to 1.44 at 36 to 41 inches; P-381 increases from 1.37 in the surface to 1.49 at 28-36 inches and P-385 increases from 1.26 in the surface to 1.39 at 30 to 36 inches. Such differences are greatest in the surface horizons where the volume weight is lowest, and these differences gradually decrease with depth. Organic agents both living and dead are probably the most important factors reducing the volume weight of the surface horizons.

There is a general relationship of higher volume weights for the different soil horizons of the forest-derived soils of the paha than for the prairie-derived soils. This relationship also is true for the Fayette silt loam, No. 16, versus the Tama silt loam, P-27, as the volume weights of the forest-derived Fayette soil are higher than those of the prairie-derived Tama soil. A comparison of the volume weights for the Brunizem soil on the paha, profile P-383, and the Tama silt loam, profile P-27, shows that there is little difference between the two soils. The Gray-Brown Podzol soil on the paha, profile P-382, was also found to be very similar to the Fayette silt loam profile No. 16.

In addition to the seven soil profiles occurring on paha, a Tama soil profile from Tama County, a Fayette soil profile from Jackson County, a calcareous loess sample from Marshall County, a calcareous oxidized till sample from Marshall County and a calcareous unoxidized till sample from Marshall County were sampled for volume weight determinations for comparative purposes. Both the Tama and Fayette profiles showed an increasing volume weight with depth.

Other investigators (72) have shown that volume weight is not constant but varies with the season and moisture content at time of measurement. A study of the variations reported by these investigators shows that volume weight usually, but not always, varies inversely with moisture content. However, variations due to moisture content can be avoided by sampling the soils at field capacity. The soils on the paha were all sampled at their approximate field capacities.

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*Calculated as follows: Cylinder #1: Volume $= \pi r^2 h$ = 3.1416 (3.6 cm)^2(6.4 cm) = 260.45cc. Cylinder #2: Volume = $\pi r^2 h$ = 3.1416 (3.5cm)2(6.35cm) = 244.25cc.

**Volume weight = $\frac{\text{Wt. oven dry soil}}{\text{Wt. equal volume of water}}$

Porosity. In addition to the three volume weight samples, four smaller porosity soil samples (volume = 57.75 cm^3) from representative horizons were obtained at the same time the profiles were sampled.

The sleeves containing core samples for porosity determinations were saturated and then placed on a moisture plate at a tension of 40 cm. Baver (8) and Nelson and Baver (29) state that the mo sture removed under a tension of 40 cm. is a reliable estimate of noncapillary porosity (the term noncapillary porosity is now known as aeration porosity) of the soil. At the end of 24 hours the core samples were removed, weighed, resaturated with distilled water, their permeability determined, oven dried for 36 to 48 hours, and weighed for the last time. From the data obtained, the aeration, capillary porosities and total porosities, and volume of soil solids were calculated. The average results of the four determinations for each horizon expressed on a volume basis are presented in Table 2.

Table 1. Volume weights, aeration and capillary porosity data of seven soil profiles on paha, Tama profile, Fayette profile, and several loess and till samples.

Depth (inches)	Horizon designation	Volume weight	Porosity in percent			Soil Solids
			Aeration	Capillary	Total	
		P-380 (Minimal Brunizem)				
2-5	A_{11}	1.38	10.0	37.8	47.8	52.2
12-18	B_{11}	1.32	16.9	33.3	50.2	49.8
18-24	B_{12}	1.29	17.2	34.1	51.3	48.7
30-36	C_{12}	1.38	11.0	36.9	47.9	52.1
		P-381 (Medial Brunizem-Gray Brown Podzol Intergrade)				
2-6	A_{11}	1.37	7.3	41.0	48.3	51.7
6-9	A_3B_1	1.32	10.1	40.1	50.2	49.8
9-12	B_{21}	1.42	6.7	39.3	46.0	54.0
17-22	B_{23}	1.42	5.4	40.8	46.2	53.8
28-36	B_{32}	1.49	4.6	39.1	43.7	56.3
		P-382 (Medial Gray Brown Podzol)				
4-10	A_{21}	1.34	7.7	40.1	47.8	52.2
14-18	B_{21}	1.44	6.2	39.5	45.7	54.3
24-30	B_{31}	1.49	8.5	35.1	43.6	56.4
36-42	B_{33}	1.44	6.7	39.1	45.8	54.2
		P-383 (Minimal Brunizem)				
2-7	A_{11}	1.35	10.7	38.5	49.2	50.8
12-15	A_3B_1	1.20	6.2	38.5	54.7	45.3
18-22	B_{11}	1.19	17.7	37.5	55.2	44.8
26-30	B_{13}	1.21	17.3	38.1	55.4	44.6
36-40	C_{12}	1.32	10.5	40.8	51.3	48.7

Table 1(Cont'd)

Depth (inches)	Horizon designation	Volume weight	Porosity in percent			Soil Solids
			Aeration	Capillary	Total	
		P-384 (Medial Brunizem)				
4-9	A_3B_1	1.26	11.5	40.8	52.3	47.7
9-13	B_{11}	1.31	12.3	38.1	50.4	49.6
16-21	B_{21}	1.35	11.1	38.1	49.2	50.8
26-31	B_{23}	1.40	11.5	36.5	47.0	53.0
36-41	B_{32}	1.44	4.4	40.1	45.5	54.5
53-60	B_{35}	1.41	6.7	39.8	46.5	53.5
		P-385 (Minimal Brunizem)				
2-5	A_{11}	1.26	16.8	35.6	52.4	47.6
8-11	A_3B_1	1.14	21.4	35.5	56.9	43.1
18-24	B_{12}	1.25	17.9	34.8	52.7	47.3
30-36	C_{12}	1.39	12.3	35.4	47.7	52.3
42-48	C_{14}	1.37	9.4	38.9	48.3	51.7
		P-386 (Regosol)				
4-8	A_{12}	1.07	18.4	36.8	55.2	44.8
13-19	C_{ca}	1.21	15.3	36.5	51.8	48.2
25-31	C_{ca}	1.25	16.7	36.1	52.8	47.2
37-47	C_{ca}	1.37	4.8	43.4	48.2	51.8
		P-27 Tama				
6-9	A_{12}	1.05	22.2	38.1	60.3	39.7
12-15	A_3B_1	1.26	14.8	37.7	52.5	47.5
21-24	B_{21}	1.26	11.6	41.0	52.6	47.4
33-36	B_{22}	1.35	9.0	39.9	48.9	51.1
42-45	B_{31}	1.34	8.5	41.1	49.6	50.4
		P-16 Fayette				
2-5	A_{21}	1.24	18.2	35.1	53.3	46.7
12-15	B_{11}	1.30	14.3	36.8	51.1	48.9
21-24	B_{12}	1.45	9.1	36.1	45.2	54.8
30-33	B_{13}	1.48	6.6	37.9	44.5	55.5
39-42	B_{21}	1.47	4.5	39.7	44.2	55.8

	Depth (inches)	Volume weight	Porosity in percent			Soil Solids
			Aeration	Capillary	Total	
		Marshall County Loess				
Loess	6'	1.52	.9	41.9	42.8	57.2
Oxid. till	16'	1.61	6.0	33.2	39.2	60.8
Unoxid. till	28'	1.67	1.0	36.1	37.1	62.9

Table 2. Permeabilities of seven soil profiles on paha, Tama profile, Fayette profile, and several loess and till samples from Marshall County, and several loess samples from Monona County.

Horizon number	Depth (inches)	Horizon designation	Permeability coefficient (K) cm/sec	inches/hr	inches/day
P 381 (Medial Brunizem-Gray Brown Podzol Intergrade)					
1	2-6	A_{11}	.0012	1.71	41.
2	6-9	A_3B_1	.0021	2.98	72.
3	9-12	B_{21}	.008	11.33	272.
4	17-22	B_{23}	.0010	1.42	34.
5	28-36	B_{32}	.0015	2.13	51.
P-382 (Medial Gray Brown Podzol)					
1	4-10	A_{21}	.032	45.36	1089.
2	14-18	B_{21}	.0009	1.28	30.7
3	24-30	B_{31}	.0015	2.13	51.
4	36-42	B_{33}	.0059	8.29	199.
P 383 (Minimal Brunizem)					
1	2-7	A_{11}	.0054	7.65	184.
2	12-15	A_3B_1	.0124	17.5	420.
3	18-22	B_{11}	.0254	35.9	862.
4	26-30	B_{13}	.0162	22.89	549.
5	36-40	C_{12}	.0032	4.54	109.
P 384 (Medial Brunizem)					
1	4-9	A_3B_1	.0019	2.69	65.
2	9-13	B_{11}	.0078	11.06	265.
3	16-21	B_{21}	.0029	40.39	969.
4	26-31	B_{23}	.0084	11.84	284.
5	36-41	B_{32}	.0078	10.98	264.
6	53-60	B_{35}	.0011	1.49	36.
P 385 (Minimal Brunizem)					
1	2-5	A_{11}	.0798	113.04	2713.
2	8-11	A_3B_1	.0218	30.83	740.
3	18-24	B_{12}	.0028	3.97	95.
4	30-36	C_{12}	.0047	6.59	158.
5	42-48	C_{14}	.0200	28.35	680.
P 386 (Regosol)					
1	4-8	A_{12}	.0325	46.01	1104.
2	13-19	C_{ca}	.0258	36.5	876.
3	25-31	C_{ca}	.0041	5.81	139.
4	37-47	C_{ca}	.0014	1.91	46.
P 27 Tama silt loam					
1	6-9	A_{12}	.0204	28.91	694.
2	12-15	A_3B_1	.0162	11.48	275.
3	21-24	B_{21}	.0036	5.03	121.
4	33-36	B_{22}	.0850	12.05	289.
5	42-45	B_{31}	.0098	13.89	333.
Fayette silt loam - Jackson County					
1	2-5	A_{21}	.0103	14.53	349.
2	12-15	B_{11}	.0003	.43	10.
3	21-24	B_{12}	.0212	29.98	720.
4	30-33	B_{13}	.0094	13.32	320.
5	39-42	B_{21}	.0004	.57	14.
Loess in Marshall County					
1	6' below surface loess		.0031	4.32	104.
2	16' calc. oxid. till		.0004	.57	13.7
3	28' calc. unoxid. till		0.	0.	0.

$$\text{Per cent total porosity} = \frac{\text{Vol. of ring} - \frac{\text{Wt. of soil}}{\text{density of soil}}}{\text{Vol. of ring}} \times 100$$

or

$$\text{Per cent total porosity} = - \frac{\text{volume weight}}{\text{real specific gravity}} \times 100$$

$$\text{Per cent soil solids} = 100\,\% - \text{per cent total porosity}$$

$$\text{Per cent capillary porosity} = \frac{\text{Volume of water lost in oven (105°C) after core sample had been subjected to 40 cm of water tension}}{\text{Vol. of brass ring}}$$

$$\text{Per cent aeration porosity} = \text{Total porosity} - \text{capillary porosity.}$$

The data in Table 1 indicate in general a decreasing aeration porosity, an irregular capillary porosity tending somewhat to increase, decreasing total porosity, and increasing soil solids with increasing profile depth of the soils occurring on the paha. In contrast, the Tama and Fayette soil profiles exhibit a uniform increasing capillary porosity and decreasing aeration porosity with increasing profile depth. The soils occurring on the paha have a more irregular distribution of aeration and capillary porosity compared to other soils (19, 66) in Iowa developed in blanket loess areas.

The general trend in the initial stages of formation of a profile like P-384 from the parent loess on the paha is an increase in aeration porosity and total porosity, and a decrease in soil solids. Profile P-384 appears to be more highly developed than the other soils sampled on the paha, and possibly represents a developmental stage which will be reached in the future by the other prairie-derived profiles, provided, of course, that other factors of soil formation are equal.

The calcareous loess and till samples from Marshall County show very low aeration porosity values and high amounts of soil solids. This would be anticipated from the high volume weight figures for these samples.

Permeability. As previously mentioned in the section under porosity, the permeability of the four small soil samples was measured. The procedure used is the same as used by Ulrich (66) and Hunter (19), and closely follows that described by Wilson, Riecken, and Browning (71). The average values of the four samples from each horizon of each profile, plus the deep loess and till samples are presented in Table 2. No permeability data are given for profile P-380 because of damage to these samples by insects in the laboratory.

The permeability values presented in Table 2 should be interpreted on a qualitative rather than a quantitative basis. Considerable variation from sample to sample within horizons was the rule rather than the exception. The data show the prairie-derived soils on the paha to have a somewhat greater permeability throughout most of the profile than the forest-derived soils on the paha. The variability of the data is so great, however, that no conclusions can be reached regarding the significance

of the differences. The Gray-Brown Podzol on the paha, profile P-382, has permeability values which decrease to a minimum in the A_2 horizon. The Fayette silt loam, profile No.16, also has lowest permeability values in the A_2 horizon. Although these two forest-derived soils have permeability values which have a somewhat similar trend with depth in the profile, no conclusions as to differences between them can be reached on the basis of the permeability data. The prairie-derived soil on the paha, P-383, and the prairie-derived soil on blanket loess, Tama silt loam, profile P-27, both have rather high permeability values throughout their respective profiles. The permeability data for these soils does not serve as a basis for determining soil differences which may exist.

To standardize permeability measurements (49) cores which contained worm holes or root channels were discarded.

The results reported in Table 2 are based on the following formula:

$$Q = \frac{K H A}{L}$$

where: Q = quantity of water in ml/sec
L = length of core in cm (3.8 cm)
H = hydrostatic head in cm (5.0 cm)
A = cross-sectional areas in sq cm ($3.14 \times 2.2^2 = 15.20$ cm^2)
K = permeability coefficient per unit hydraulic gradient.

Rearranging: $$K = \frac{L}{HA} Q$$

and: $$K(\text{cm/sec}) = \frac{3.8}{(5.0)(15.20)} \qquad Q = 0.05\, Q$$

$$K(\text{in/hr}) = \frac{(3.8)(3600)}{(5.0(15.20(2.54)} \qquad Q = 70.87\, Q$$

$$K(\text{in/day}) = (K \text{ in/hr})(24)$$

Other investigators (8) have shown a correlation between aeration porosity and permeability. Ulrich (66) and Hunter (19) report from their studies that decrease in permeability was accompanied by a decrease in aeration porosity and an increase in clay accumulation. It is probable that there is a range of optimum clay content for favorable structure and maximum permeability. In some cases the clay content may not be sufficient for the most favorable structure and aggregation. This may explain low permeability values for soil horizons with low clay content such as are found in some of the soils on the paha. Another factor which may have considerable influence on soil permeability, is the presence in the soil of insects, worms, burrowing animals, and crotovinas. It has been observed that the soils of the paha contain many insects and animals, all of which doubtless influence the permeability of the soils on the paha. It should be noted that the permeability method used in this study may not actually indicate the true permeability of the soil under field conditions. It is possible that some of the low permeability values obtained for subsoil horizons may be a result of a breakdown or puddling of the structural aggregates where the water is introduced into the soil core. Such a

puddling effect could result in lower permeability values which would not be a reflection of the true permeability of the soil under field conditions. With the exception of profile P-384, the soils on the paha have weakly developed structure. However, the Tama and Fayette soils developed in blanket loess that were sampled conformed to Ulrich's (66) observation and contained minimum permeability in the zone of maximum clay accumulations, the B_2 horizon.

The high permeability of the surface horizons seems to be correlated with the virgin condition. In cases where the permeability of the surface is very high, the soil profile was obtained from virgin areas. In such areas the abundance of roots and worm holes made it impossible to select cores which did not contain channels of one sort or another.

Chemical Studies

Soil reaction or pH. The pH of the samples was determined by use of the glass electrode and the results are shown in Table 3.

With the exception of one horizon in profile P-383 and the entire profile P-386, each profile was acid in reaction in all of its horizons. The soils on the paha were more acid in the surface horizons than in the B horizons in some instances, but in others the surface layers were less acid than the B horizons. In general, the soil horizons became less acid at depths of 36 inches than the horizons above. Advancing profile development seems to accompany increasing soil acidity. For example, profiles P-381, P-382, and P-384 were more acid throughout their profile depth than the other soils on the paha. These three profiles were the only ones sufficiently well developed to be classed as medial for their respective Great Soil Groups. P-381 reached a minimum pH of 5.1 at 17 to 22 inches in depth, P-382 a minimum pH of 5.3 at 18 to 30 inches in depth, and P-384, the most well developed of all the profiles, reached a minimum pH of 4.9 at a depth of 26 to 31 inches. However, profile P-385 is not well developed and yet is more acid than profile P-384. This is difficult to explain on any basis other than possible differences in lime content of the parent material when it was deposited. Most of the profiles are most acid in the B horizon, but profiles P-383 and P-385 are the exceptions to this, being most acid in the A horizons.

There are no consistent differences in pH between the Brunizem soils and the Gray-Brown Podzol soils on the paha. Some of the Brunizem soils have higher pH values throughout their profile than the forest-derived soils. On the other hand, some of the Brunizem soils have pH values equally low or lower than the forest-derived soils. The Tama silt loam, profile P-27, has higher pH values throughout the entire profile than does the Fayette silt loam No. 16. The greatest differences in pH between the two soils occur in the lower portion of the A horizon and the upper portion of the B horizon. For example, in the A_2 horizon of the Fayette soil the pH is 4.6 compared to a pH of 5.3 in the A_3 horizon of the Tama soil. However, as profile depth increases the pH differences become smaller, and the pH is about the same at depths of 60 inches or more.

Available phosphorus and potassium. Available phosphorus was determined by a modification of the Bray No. 1 method and available potassium by use of the sodium perchlorate method. These methods are currently being used by the Soil Testing Laboratory, Iowa State College, Ames.

The result of the P determinations, shown in Table 3, indicate considerable variability as to available P in the soils occurring on the paha. Profile P-380 shows a very low supply of available P in the upper horizons. Profiles P-381, P-383, P-384, and P-386 are low in P in the upper horizons. Profiles P-382 and P-385 are medium in the upper horizons. All the soil profiles sampled on the paha would require applications of P for maximum production of corn, small grain, and legume crops.

The results from the available K determinations, given in Table 3, of the soils on the paha indicate a rather low level of available K for all but one horizon of one soil, the surface horizon of P-384. Profile P-383 is very low in available K throughout the entire profile depth.

Recent data of the Soil Testing Laboratory at Ames for 940 samples tested from Blackhawk County showed that only 16.3 per cent of the samples had a medium-high or high amount of available potassium. Data for

Table 3. pH and available phosphorus and potassium of seven soil profiles on paha.

Depth (inches)	Horizon designation	Available P, pounds/acre	Available K, pounds/acre	pH
	P-380 (Minimal Brunizem)			
2-5	A_{11}	2.0	165	5.95
5-9	A_{12}	1.0	160	6.1
9-12	A_3B_1	1.0	165	6.3
12-18	B_{11}	2.5	160	6.3
18-24	B_{12}	18.0	170	6.25
24-30	C_{11}	15.0	160	6.25
30-36	C_{12}	19.0	160	5.95
	P-381 (Medial Brunizem-Gray Brown Podzol Intergrade)			
0-6	A_{11}	3.5	175	6.35
6-9	A_3B_1	4.5	120	6.1
9-12	B_{21}	4.0	125	5.8
12-17	B_{22}	3.5	110	5.45
17-22	B_{23}	2.5	105	5.1
22-28	B_{31}	9.5	105	5.35
28-36	B_{32}	26.5	110	5.45
36-48	C_{11}	51.0	125	5.6
	P-382 (Medial Gray Brown Podzol)			
0-4	A_{11}	8.5	160	6.5
4-10	A_{21}	9.0	100	5.7
10-14	B_{11}	7.5	140	5.4
14-18	B_{21}	9.5	140	5.4
18-24	B_{22}	12.0	145	5.3
24-30	B_{31}	29.5	160	5.3
30-36	B_{32}	37.0	150	5.35
36-42	B_{33}	42.0	125	5.45
42-48	C_{11}	33.0	150	5.6
48-60	C_{12}	19.0	115	5.8

Table 3 (Cont'd)

Depth (inches)	Horizon designation	Available P, pounds/acre	Available K, pounds/acre	pH
	P-383 (Minimal Brunizem)			
2-7	A_{11}	6.5	110	5.65
7-12	A_{12}	4.0	95	5.9
12-15	A_3B_1	3.5	85	6.2
15-18	A_3B_1	3.5	105	6.05
18-22	B_{11}	4.5	105	6.45
22-26	B_{12}	5.0	105	6.4
26-30	B_{13}	7.0	110	6.45
30-36	C_{11}	7.5	85	6.5
36-40	C_{12}	12.0	95	6.6
40-50	C_{13}	12.0	85	6.6
50 +	C_{ca}	3.0	85	8.4
	P-384 (Medial Brunizem)			
0-4	A_{11}	4.0	400	5.8
4-9	A_3B_1	2.0	200	6.35
9-13	B_{11}	6.5	220	6.15
13-16	B_{12}	4.0	210	6.05
16-21	B_{21}	1.0	160	5.2
21-26	B_{22}	3.5	140	5.15
26-31	B_{23}	19.0	160	4.95
31-36	B_{31}	25.0	130	5.2
36-41	B_{32}	45.0	140	5.2
41-47	B_3C_1	42.0	130	5.5
47-53	B_3C_1	26.5	130	5.6
53-60	B_3C_1	29.5	115	5.7
	P-385 (Minimal Brunizem)			
2-5	A_{11}	8.0	225	5.0
5-8	A_{12}	18.0	200	4.8
8-11	A_3B_1	21.0	210	4.8
11-14	A_3B_1	2.5	130	5.6
14-18	B_{11}	5.0	175	5.45
18-24	B_{12}	19.0	200	5.25
24-30	C_{11}	24.0	125	5.7
30-36	C_{12}	29.5	240	5.7
36-42	C_{13}	26.5	150	5.95
42-48	C_{14}	24.0	200	6.05
	P-386 (Regosol)			
0-4	A_{11}	4.5	170	7.6
4-8	A_{12}	2.0	140	7.8
8-13	A_3C_{ca}	1.0	70	8.0
13-19	C_{ca}	1.0	65	8.0
19-25	C_{ca}	1.0	130	8.1
25-31	C_{ca}	1.0	75	8.1
31-37	C_{ca}	1.0	110	8.25
37-47	C_{ca}	1.0	90	8.3

samples from Clayton County showed 29.5 per cent of 1518 samples tested had an available potassium content of medium-high to high. Tama County data showed 56.1 per cent of 262 samples tested had a medium-high or high content of available potassium. The soils in Blackhawk County are mostly derived from Iowan glacial drift whereas the soils in Clayton County are derived mostly from Wisconsin loess as are the soils in Tama County.

The rating of available potassium content by the Soil Testing Laboratory is as follows:

Rating (for available potassium)	Available potassium (lbs. per acre)
High	above 250
Medium-high	200-249
Medium	150-199
Low	100-149
Very low	100

From the data on the soils of the paha it is evident that they approximate rather closely the available potassium content of the Iowan glacial drift-derived soils or the Wisconsin loess-derived soils from northeast Iowa. Profile P-384 would rate high as to available potassium content, P-385 as medium-high, P-380, P-381, P-382, and P-386 as medium, and P-383 as low. The available phosphorus and potassium data show that there are no consistent differences between the forest-derived soils and the prairie-derived soils on the paha.

It is of interest to note that the available potassium content of the surface soils on the paha seems to be most similar to the Iowan glacial drift-derived soils or the Wisconsin loess-derived soils of northeast Iowa. They seem to be much lower on the average in available potassium than are the loess-derived soils of southeast Iowa. It is recognized that the number of observations of soils on the paha is too small to permit drawing any definite conclusions.

Most of the samples tested by the Soil Testing Laboratory at Ames are from cultivated fields. However, some samples from permanent pastures which have been tested show that pasture or virgin areas tend to give higher amounts of available potassium by as much as 100 pounds or more for comparable soils. As only one profile, P-386, was sampled in a cultivated field, it seems reasonable to expect that the available potassium contents for the soils on the paha might be even lower had they been secured from cultivated fields. This may be taken as further evidence which might help substantiate the contention that the loess of the paha originated locally from the adjacent Iowan drift plain and is not the same as the loess of southeast Iowa.

The available K figures seem to indicate again that profile P-384 is considerably different from the other soils found on the paha. Profile P-384 shows more development than the other profiles sampled and also other profiles observed on the paha. Perhaps this profile is the result of local accumulation of loess which was higher in finer material, silt plus clay, and lower in sand than was the case for the loess of the other

paha. No data are available, however, from this study to draw any conclusions as to the reasons for the existing differences.

Exchangeable cations. In order to study further the relationship between commonly occurring prairie- and forest-derived soils on the paha and prairie- and forest-derived soils developed from blanket loess, the exchangeable hydrogen, calcium and magnesium were determined on selected horizons of two soil profiles developed from loess on paha by methods outlined by Black (9). Similar data for the Tama series (48), P-27, and a profile of the Fayette series (69) were already available. Samples obtained from the same two locations were used in this study for measurements of porosity, volume weight, and permeability.

Exchangeable calcium as shown in Table 4 is high in the A_1 horizon of both prairie- and forest-derived profiles. It increases in the B horizon and becomes as high or higher in the C horizon as it is in the A horizon. For example, the Tama silt loam profile P-27, has 11.3 milliequivalents of exchangeable calcium in the A_1 horizon, 15.0 in the B_2 horizon, and 13.4 in the C horizon. The exchangeable calcium content of the prairie-derived soil on the paha, profile P-383, is very similar to that of the Tama soil. The Fayette silt loam profile No. 16 has 8.2 milliequivalents of calcium in the A_1 horizon, 1.9 in the A_2 horizon, 8.3 in the B_2 horizon, and 10.5 in the C horizon. Profile P-382, the forest-derived soil on the paha, has a similar trend of exchangeable calcium content with profile depth except that it has somewhat greater amounts of exchangeable calcium in comparable soil horizons. It has 8.87 milliequivalents of exchangeable calcium in the A_1 horizon, 5.6 in the A_2 horizon, 8.96 in the B_2 horizon, and 9.84 in the C horizon. The exchangeable magnesium content is lower than the exchangeable calcium content in all profiles of the soils studied. The exchangeable magnesium content is lowest in the A horizons of the prairie- and forest-derived soils on the paha, and the Tama silt loam, P-27, and increases with profile depth. The Fayette silt loam profile No. 16 decreases from an exchangeable magnesium content of 4.1 milliequivalents in the surface to 1.3 in the upper B horizon and then increases to 5.1 in the C horizon. Exchangeable hydrogen in the two forest-derived profiles, P-382 and the Fayette silt loam No. 16, is least in the A_1 horizon and increases with depth to the C horizon where it again decreases. In prairie-derived profiles the greatest amount of exchangeable hydrogen is in the A_1 horizon, gradually decreasing to a small amount in the C horizon.

The per cent base saturation and the ratio of exchangeable calcium to magnesium is similar for the forest-derived soil profile of the paha and Fayette silt loam No. 16. Likewise the per cent base saturation and calcium to magnesium ratio of the prairie-derived profile of the paha and the Tama silt loam P-27, are similar. A lowered exchangeable calcium to magnesium ratio has sometimes been suggested as a criteria of more intense or advanced soil weathering (10). However, the differences of the exchangeable calcium to magnesium ratio between any of the profiles listed in Table 4 are small. From this it may be inferred that the chemical and mineralogical weathering for the soils is at about the same stage. More information is needed as to the significance of differences in chemical properties between soils before the differences such as were found between the soils of the paha and soils of the blanket loess areas can be correctly evaluated.

Table 4. Exchangeable H, Ca, Mg, Ca/Mg ratio, and base saturation of selected layers of two paha loess-derived soils and a profile each of Tama and Fayette series.

Profile	Depth (inches)	Exch. H me/100 g. soil	Exch. Ca me/100 g. soil	Exch. Mg me/100 g. soil	Ratio Ca/Mg	Base saturation percent
P-382	0-4	1.4	8.9	2.4	3.8	89
	4-10	2.6	5.6	2.3	2.5	75
	14-18	3.8	9.8	4.6	2.1	79
	24-30	3.8	9.0	4.3	2.1	78
	48-60	2.4	9.8	4.5	2.2	85
No. 16, Fayette silt loam (45)	0-3½	4.5	8.2	4.1	2.0	73
	3½-6½	6.5	1.9	1.8	1.1	36
	9½-12½	6.5	1.5	1.3	1.2	30
	22-26	7.6	6.8	3.3	2.1	57
	26-29½	8.0	8.3	3.8	2.2	62
	54½-58½	5.1	10.5	5.1	2.1	75
P-383	2-7	5.3	9.8	3.6	2.7	71
	7-12	3.7	11.2	3.9	2.9	80
	18-22	2.3	10.8	4.2	2.6	87
	26-30	1.9	10.7	4.5	2.4	89
	50-60	.4	Free lime	5.3	9.4	100
P-27, Tama silt loam (44)	0-6	8.0	11.3	4.1	2.7	67
	9-12	5.2	13.1	4.8	2.7	78
	18-21	4.1	12.9	6.1	2.1	83
	24-27	3.3	15.0	6.5	2.3	87
	48-54	1.0	13.4			

DISCUSSION

Although the presence of paha has been recognized for more than 70 years (27), no coordinated effort had been made to chart their frequency and distribution. They have been studied and discussed by earlier workers as geological phenomena of interest primarily because of their peculiarities. The explanation has been sought for their origin, topography, orientation, distribution, intrinsic composition, and characteristics in general. Until recently, soils workers attached no special significance to paha as regards classification or genesis of soils occurring on them.

To determine the importance of the paha to soil classification, it was considered necessary to add to the knowledge of their distribution. Mapping of the paha, in reconnaissance, demonstrated they they are more widely distributed than had been formerly thought. More than 160 paha have been located during the field phases of this study and their distribution within the Iowan drift borders is illustrated in Fig. 2. Doubtless, detailed traverses in the field would reveal considerable numbers of additional paha. From field observations the writer believes that there are also paha in the Iowan drift area of northwest Iowa. However, charting their distribution would entail some effort because the blanket loess is quite thick in the area. Recognizing the distribution of paha in this area is also not of such importance as in northeast Iowa where the loess is thin or absent in the areas adjacent to the paha. The writer has also observed paha in considerable numbers on the Iowan drift in Illinois and

Minnesota. The results of this portion of the study indicate that paha are numerous enough to warrant attention from the aspect of soil classification and soil management.

The traverse of deep borings made across an isolated paha in Grundy County illustrated the relationship of the loess thickness on the paha to the loess thickness on the Iowan till. On this particular paha the thickness of eolian material was uniform from the crest of the paha to the lower portion of the slope whereas it thinned rather rapidly from the crest to the foot of the slope on the south side. The Iowan till was encountered beneath the loess at about the same depth on each side of the Kansan till nucleus of the paha. The Kansan till nucleus was found to contain a buried fossil soil on its surface with a sequence of normal horizons, possibly an intergrade between Gray Brown Podzol and Red Podzol. In one location the Iowan contained an incorporated Kansan till "boulder", indicating a possible plowing and scouring of a portion of the Kansan high by the Iowan glacier. It is interpreted here that the presence of the buried fossil soil with its complement of normal horizons on the Kansan till high indicates that the Iowan glacier did not override the Kansan till at that place. An overriding of the Kansan nucleus by the Iowan glacier would likely have resulted in plowing or disturbing the normal soil profile formed on the Kansan till. Furthermore, no fresh till was encountered above or in the surface of the buried Kansan till-derived soil here, or in the buried soil nucleus of other paha, as might have been expected had the Kansan been overridden. No fresh pebbles of any kind were encountered either immediately below the loess or in the surface of the buried Kansan till-derived soil.

The loess on the Iowan till in the immediate vicinity of the paha was found to be thin, averaging about 2 feet thick. Although this situation by no means holds true for all the paha, more often than not the loess adjacent to the paha is of this order of thickness, namely 1-3 feet.

The high point of the Kansan nucleus is only about 15 feet higher than the highest point of the surface of the adjacent Iowan till. This represents a very small prominence in elevation not to have been overridden by the Iowan glacier. However, no measurement is available of the thickness of the Iowan till adjacent to or at some small distance, say 100 to 500 feet, from the paha. Therefore, the Kansan prominence may have been rather high in relation to this pre-Iowan surface some distance away from the present recorded Kansan till nucleus. Consequently, the height of the Iowan drift on the side of the Kansan nucleus may still represent a considerable thickness of Iowan till. The Iowan till reposing at the same elevation on both sides of the Kansan nucleus may be a further indication that the Iowan ice moved around the Kansan prominence and did not override it.

The problem of the paha from geological aspects has been recognized (33) as composed of two parts, namely, the origin of the till nucleus and of similar pahoid hills with no loess, and the origin of the loess cap. Concerning the former, an attempt was made to determine the comparative elevations of paha to hills of similar shape and elevation, and to the Iowan drift plain. The results obtained from traverses with an altimeter reveal in some instances high points on the Iowan drift which are only a few feet below high points on a paha. Doubtless the height of the Iowan

drift (Fig. 5) is greater in these instances than that of the pre-Iowan nucleus when the thickness of loess on the paha is deducted from the total elevation. In other instances, which are the most common, the elevation of the paha will be higher by 20 to 50 feet or more than adjacent hills of pahoid form which have little or no loess as in Figs.5 and 6. In all instances observed in the field the pahoid hills with no loess or only a small amount comparable to that found over the pebble band on the adjacent Iowan drift plain. Wherever the paha have been observed in this study, the material was always found to be a pre-Iowan material that showed no evidence of having been overridden by the Iowan glacier. The nuclei have almost invariably been of Kansan till, but a few paha have been found to have rock nuclei upon which is found a residual soil.

The writer recognizes the conflict between his views and the views of many Pleistocene geologists regarding the formation of paha and the thickness of glacial ice. On May 11, 1952, the writer led a field tour of the midwest section of the Friends of the Pleistocene. This group is composed of Pleistocene geologists in the midwest who meet once a year to examine in the field the research evidence of people working on geological problems. Upon examination of the evidence in the field, the group generally accepted the relationship of the loess to the underlying weathered core, the eolian origin of the loess, and the absence of fresh materials upon the weathered pre-Iowan soil.

However, considerable resistance was encountered to the hypothesis that the paha were formed because of pre-Iowan highs not overridden by the Iowan ice. It was contended that in order for glaciation to have occurred, the ice must have been thick enough to override any local Kansan highs.

In answer to the above objection the writer brings forth these points: (A) the presence of Kansan re-entrants into the Iowan area, like that in Linn and Benton Counties, are due to the higher elevation of the Kansan drift plain and the failure of the Iowan ice to override these highs,* (B) the paha are concentrated in the border areas of the Iowan drift where the ice was thinner than within the drift sheet (Fig. 2), (C) no fresh till or pebbles are encountered on the pre-Iowan soils of the paha core.

It has already been pointed out that other points become difficult to explain, such as adjacent highs of Iowan till with no loess accumulation and high areas of deep loess with no Iowan till present. This can be explained, however, if one accepts the possibility that the glacial ice was not of uniform thickness everywhere and that some high points were not overridden by the ice. The presence of the large Kansan re-entrants represents, in the opinion of the writer, what has happened on a large areal scale, while the origination of the paha represents the same mechanism on a small scale.

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*The problem of explaining the Iowan salients is one many geologists pose when the Iowan is referred to as 'thin' ice. These salients, the pebble band, the paha, and many other features of the Iowan are anomalies which have perplexed geologists for years. The writer attempts to explain only the origination of the paha and their associated soils, leaving it up to some qualified geologist to 'make his fame' by explaining the Iowan pebble band, etc.

On the basis of field observations and studies, the conclusion reached here is that hills of pahoid form with no loess usually represent pre-Iowan highs that have been overridden and covered by the Iowan till. The vegetation was presumably obliterated by glacial action and no catchment was provided for the materials which must have been moved about by the wind when the Iowan drift plain was still bare of vegetation. Paha, on the other hand, originated, it seems, because the pre-Iowan highs which form their nuclei were not overridden by the Iowan glacier. Hence, their vegetation, either living or dead, forest or prairie, remained as a source of lodgement for the materials moved about on the unvegetated Iowan plain by the wind. The occurrence of pipestems at the contact between the loess and the pre-Iowan soil is indicative of live vegetation. Snails incorporated throughout the loess matrix in some paha also point to the gradual accumulation of loess around a living vegetation.

The orientation of the paha may be explained by the fact that the ice was moving in a southeasterly direction and would tend to leave elongate protrusions shaped in that direction. But possibly most important was the direction of the prevailing wind, NW to SE, which would orient materials in that direction when vegetation provided a lodgement. This is borne out by observations where the southeast end of the paha loess blanket has streamed out on top of the Iowan drift.

The reason for the presence of the pre-Iowan high, predominantly Kansan in character, is not apparent at this time. The nuclei of the paha have been sometimes explained as drumlins (16, 33) which have been thickly coated with loess, but lack of Kansan drumlins in other Kansan areas makes this seem unlikely. Still another explanation of the paha nuclei is that they are the result of accretions of pre-Iowan till around a high rock prominence or outcrop. However, borings through a paha to 140 feet showed only glacial drift (32).

That vegetation likely existed on the pre-Iowan nuclei of the paha is borne out by the presence of buried soils on the surface of the nuclei. Had there been no vegetation on these nuclei immediately preceding or during the advance of the Iowan glacier it is likely that the solum of the pre-Iowan landscape would have been removed by geologic erosion. The buried soils on the paha are morphologically similar to the buried soils on the Kansan drift outside the Iowan drift border. These buried soils outside the Iowan drift border were covered only by the Wisconsin loess (22). The buried soils on the paha represent soils which were a reflection of the dominant soil forming factors operative at that locale. Consequently, buried soils similar to Gray Brown Podzolic, Brunizem, Weisenboden, and Planosol soils such as exist on the present land surface are encountered. It is of ecological interest to note that although several great soil groups are represented by the buried soils, in most instances the buried soils give evidence of being developed under forest vegetation rather than grass. Conversely, in the Iowan drift area today, most of the modern soil profiles were formed under a grass vegetation. Further indication of the presence of vegetation is the occurrence of numerous root pipestems at the contact of the loess and buried till-derived soil. Fossil mollusks found at the contact zone indicate that during loess deposition a vegetative environment for the faunal population existed similar to that of today (42). Prior to loess deposition the climate is assumed to be similar

to that of today. The long weathering interval may explain the heavily weathered buried soils, but it is possible that a somewhat different climate may have also been responsible.

From the morphology of the soils sampled on the paha, it appears that the soils will be confined to a few Great Soil Groups. The soils observed belong either to the Brunizem, Gray Brown Podzol, intergrades of these, and Regosol Great Soil Groups. The paha have been described as being originally forested (27). But it is evident from soils information that many of the paha observed in this study must have had a native vegetation of prairie for a considerable portion of the period since the loess was deposited, as no evidence of the soil structure usually found in the B horizon of Gray Brown Podzolic soils was observed. The loess on the paha represents an accumulation of loess probably predominantly Iowan in age but which may represent deposition from Iowan time to post-Mankato time. The absence of any thick mantle of loess over most of the surface of the Iowan, except on the paha, would seem to indicate that any increments of Tazewell and post-Tazewell loess, Cary and post-Cary loess, and Mankato and post-Mankato loess must have been small.

The writer submitted fossil wood samples for age determinations by radioactive carbon assays to the Institute for Nuclear Studies at the University of Chicago (5). These fossil wood samples were obtained from a forest bed buried in loess in Polk County beneath a Wisconsin till, now tentatively designated as Cary (37). Results of the age determinations showed the wood to be more than 17,000 years old. Because the buried loess in Polk County is likely Iowan and post-Iowan, and/or Tazewell and post-Tazewell loess, it is probably a correlative of the loess on the paha. Therefore, it seems reasonable to assume that most of the loess of the paha was deposited about 17,000 years ago (further substantiated from additional C^{14} data (37a)). The upper portion of the paha loess in which the modern soil profile is developed may be as late as post-Mankato in age, although it seems unlikely for most of the paha lie deep within the Iowan drift plain. In this area there is no indication of a sufficiently long time interval between the subages of the Wisconsin age in which to develop a profile which would serve as a marker for the different times of deposition in these paha.

Morphologically, some of the soils occurring on the paha which were sampled appear to be similar to the Monona, Tama, Downs, and Fayette series. The calcareous Regosol occurring on the paha is morphologically similar to the Ida series except that the organic zone is thicker than is normal for the Ida series. The profile is also calcareous to the surface, whereas much of the uneroded Ida series does not contain lime in the surface horizon.

The soil survey of a paha in Benton County serves to illustrate the distribution of soils of different development with topography. Minimal Brunizem soils predominated on the paha mapped and usually occurred on the steeper slopes where erosion might have been an important factor and on the slopes that are more exposed to solar radiation. In coves and on more gentle slopes the medial Brunizem soils predominated.

Particle size analysis of the different horizons showed that some profiles as P-382 and P-384 have an accumulation of clay in the B horizon, but that other profiles as P-380, P-383, P-385, and P-386 had little or

no concentration of clay in the B horizon. Profile P-385 exhibits considerable variability in amounts of clay in successive horizons. Irregular distribution of clay in cases like this may be a reflection of differences which existed in the original unweathered parent material.

Sorting of the loess is very poor in all the profiles with the exception of profile P-384. In this profile better sorting is evident. Assuming the same time for development of this profile as the other profiles, the higher proportion of clay and fine silt contained in the upper portion of the original parent material is likely to have been the cause of its medial development. The forest-derived soil sampled on a paha exhibited poor sorting compared to the other soils on the paha.

The poor sorting of the loess on the paha is difficult to explain, for even coarse loess close to its source has been shown to be rather well sorted. In Illinois, Smith (47) found in his Traverse 1 that at 0.6 miles from the bluffs the loess contained 18.7 per cent sand and more than 70 per cent silt. But at 4.5 miles from the bluffs the loess contained 2.7 per cent sand and more than 80 per cent silt. At greater distances the loess contained no sand with a silt content of about 80 and 90 per cent. In his Traverse 2 he found 1.6 per cent sand and more than 90 per cent silt at 0.1 miles from the bluff, and at greater distances no sand and a silt content of about 80 to 90 per cent. This is a great contrast to the soils of the paha where the sand content is generally high and the silt content averages about 50 per cent. The mechanical analyses of the soils on the paha may suggest a possible credence to the contention of Scholtes and Smith (40) that at least a part of the parent material of the soils on the paha was deposited as sand, and sand sized aggregates of silt and clay. It should be noted that the data of Smith (47) showed that the loess contained appreciable amounts of sand only relatively close to the source. Beyond 4.5 miles from the loess source he found no sand in the loess. From this data one may interpret that the loess of the paha which contains large amounts of sand, averaging about 30 per cent total sand, must have had its source close to the locale of the present paha. It should be noted that many of the soils derived from Iowan glacial drift have a particle size distribution (35) similar to the soils of the paha.

With the development of a textural profile certain physical changes accompany soil development. The volume weight of the C horizon indicates that the parent material had a medium high volume weight when deposited. The general trend was an increase in volume weight from the surface to the parent material or C horizon. These changes are greatest in the immediate surface horizons and decrease with depth. However, profiles which have poorly sorted loess as parent materials like profiles P-380, P-383, and P-385 have volume weight which are variable in much the same manner as the amount of clay varies. None of the soils on the paha have horizons as dense as the till samples from Marshall County in central Iowa. The density of both the loess and till samples from that locality are the highest of any soil layer sampled.

The porosity data reveal a favorable porosity relationship in all the profiles from the paha. Assuming an aeration porosity of about 5 per cent or more and permeability of about 2 inches per hour or more is favorable (19), than it seems likely that most of the soils on the paha are adapted to level terraces provided the rainfail pattern is similar.

The soils developed under a forest or partial forest vegetation have a slightly lower aeration porosity than the soils developed under a prairie vegetation. This relationship also holds true for the Tama versus the Fayette soil profiles where the Tama profile has more favorable porosity than the Fayette profile. The lower aeration porosity of the forest-derived profiles is reflected in a larger volume of soil solids and a lower permeability. The permeability of the forest-derived profiles is generally lower than that of the prairie-derived profiles.

The almost complete absence of mottlings in the soils of the paha indicates that they have good natural drainage and poor aeration on these soils is not likely to be a problem. Hunter (19) concluded that permeability of certain prairie-derived soils studied was adequate to permit the use of level terraces for erosion control and water conservation. Although study of climatic data should be made before reaching any decisions regarding the soils of the paha, it seems safe to assume that they are at least as permeable as the soils Hunter studied. Therefore, it seems likely that practices such as contour listing, level terraces, and contouring as used in southwest Iowa could be safely used on soils of the paha. The permeability measurements do not show the rather uniform progression and regression exhibited by the soils studied by Ulrich (66) and Hunter (19), As the soils of the paha are young and poorly developed, their irregular permeabilities are not unexpected as it is commonly observed that crotovina are more prominent in minimal and medial than in advanced medial and maximal Brunizem soils.

The determinations of available phosphorus and potassium reveal an irregular distribution of both throughout the entire profile depth of most of the soils on the paha. The lack of uniformity in particle size, aeration and total porosity, permeability, pH, and available exchangeable bases seems to be a characteristic of these soils. Apparently more variability is found in soils which are not well developed and/or have a parent material not homogeneous in composition. The soils of the paha are certainly on the average not well developed and their parent material seems to be unpredictably heterogeneous for loess.

The available phosphorus and especially potassium determinations show a close correlation of the soils on the paha to the surrounding Iowan glacial till-derived soils and also the loess-derived soils of northeast Iowa. The range of amounts of available phosphorus and potassium of the soils on the paha are more similar to the Iowan glacial till-derived soils and the loess-derived soils of northeast Iowa than of the loess-derived soils of south central and southeast Iowa. This may be taken, perhaps, as further indication that the source of the paha loess was the Iowan drift plain in the locality of the paha. One profile, P-384, has a much higher content of available potassium than is found in the surface of most glacial till-derived soils in the Carrington-Clyde soil association area. The available potassium content of the surface layer of profile P-384 was more than 400 pounds per acre whereas the glacial till-derived soils in this area average about 150 to 175 pounds per acre. This higher available potassium content than the average of the paha occurring soils and the somewhat stronger profile development indicate a higher amount of clay in the original parent material in that locality, or perhaps a different loess source than the average of the paha. Further study is needed to

explain the relationship of such a soil profile to the other more commonly occurring profiles on the paha.

The comparison of the two profiles on the paha with the two profiles of established soil series reveal differences. Some of these differences may serve as a basis for excluding the soils of the paha from already established series. However, the magnitude of chemical differences between the soils on the paha and their morphological analogues, the Tama and Fayette soils, is not great. The exchangeable hydrogen, calcium, magnesium, base saturation and calcium magnesium ratio data for profile P-383 and the Tama soil, show only minor differences between the two soils. No conclusion could be reached from the data which would justify separating the soils on the basis of chemical differences. These differences between the Fayette soil and the forest-derived soil of the paha, profile P-382, are somewhat greater than in the case of the prairie-derived soils. The data reveal that the Fayette soil is higher in exchangeable hydrogen, somewhat lower in exchangeable calcium and magnesium, less saturated with bases and has somewhat lower exchangeable calcium to magnesium ratios than its morphological analogue on the paha, profile P-382. These data would not justify separation of the Fayette soil from profile P-382 on the basis of exchangeable base differences alone.

The forest-derived soil on the paha has somewhat higher calcium to magnesium ratios than does the Fayette soil. The Tama soil profile and the prairie-derived soil profile of the paha have very similar exchangeable calcium to magnesium ratios, and under the foregoing assumption would be considered about equally weathered chemically. The profile of the Tama series, however, has a higher content of clay in the B horizon than does the soil profile of the paha.

On the basis of the morphological, physical, and chemical data obtained in this study it seems that new series should be used to designate the soils of the paha. Table 5 shows the per cent base saturation and per cent clay content of the A and B horizons of several established soil series derived from loess and three soils of the paha derived from loess.

From the base saturation and clay content data it seems likely that the medial Gray Brown Podzol on the paha, P-382, is more similar to the Seaton soil than to the Fayette soil. Therefore, it is suggested that the medial Gray Brown Podzols on the paha be designated as the Seaton series on the basis of available data. The minimal Brunizem on the paha, P-383, appears likely to be more similar to the Port Byron series than to the Tama or Monona series. The Tama soil P-27 has a heavier textured profile than profile P-383 of the paha. The Monona soil P-145 has a higher per cent base saturation than the Brunizem soil of the paha. Until additional data are available it is suggested that the minimal Brunizem soil of the paha be classified with the Port Byron series. The data for the medial Brunizem soil on the paha, profile P-384, show that it is similar to the Tama soil P-27. Therefore, on the basis of present information, it is suggested that the medial Brunizem soils of the paha be classified as the Tama series. Comparison of the Regosol on the paha, profile P-386, with the Ida soil P-63 indicates that these two soils may be included in one series. The regional climatic environment of the Ida soils, however, may be enough different from that of the paha region to justify classification of the soils in the different series. Until further informa-

Table 5. Per cent base saturation and per cent clay content of the A_1 and B_2 horizons of several loess-derived soils.

Soil	Base saturation (percent)		Clay content (percent)	
	A_1 horizon	B_2 horizon	A_1 horizon	B_2 horizon
Gray Brown Podzol, P-382 (paha)	89	79	11.9	27.9
Brunizem, P-383 (paha)	72	87	21.0	21.9
Regosol, P-386 (paha	100	100	19.3	17.2
Monona (20)	96	86	27.8	30.4
Port Byron	75	85	21.0	26.0
Tama, P-27 (48)	67	88	27.5	34.2
Fayette, #16 (69)	73	71	15.7	31.0
Seaton (69)	78	71	11.3	24.3
Ida, P-63 (20)	100	100	14.8	12.7

tion is available, it is suggested that the Regosols of the paha should be classified with the Ida series.

The principal soil differences between soils of the paha and adjacent soils of the Iowan drift plain appear to result from differences in parent material and in some instances to differences in vegetation. The loess parent material of the soils of the paha, although heterogeneous for loess, is much more uniform than the parent material of the drift-derived soils. Consequently, major differences exist which are caused by differences in the nature of the parent materials. The paha were frequently forested whereas the soils on the surrounding till plain usually developed under prairie vegetation. Where vegetation differences existed the difference is reflected in the soils.

CONCLUSIONS

The following conclusions were deduced from this study:

1. The paha are numerous and widely distributed over the area of the Iowan glacial drift plain in northeast Iowa, with the bulk of the paha occurring in the southern portion of the area.

2. Detailed field work should reveal a considerable number of additional paha as yet unmapped.

3. The paha have originated because of the existence of pre-Iowan prominences, usually of Kansan till, which the Iowan glacier did not override.

4. Loess accumulated to considerable depths over the pre-Iowan highs while the areas adjacent to the paha were covered with thin amounts of loess distributed in an irregular pattern.

5. Buried soils on the Kansan nuclei of the paha, indicate development of soils comparable to some present soils exposed at the surface before deposition of the paha loess. The absence of fresh till or glacial fragments is taken as further evidence the Iowan glacier did not override the soils on the existing prominences.

6. The soils occurring on the paha are affected locally in their characteristics by the relief and vegetation at any particular point.

7. The parent material of the soils on the paha is poorly sorted loess, of which a portion may have been deposited by the wind as sand, and sand-sized aggregates of silt and clay.

8. The morphology of the soils on the paha indicates there are soils of the prairie, prairie-forest transition, Gray Brown Podzol, and Regosol Great Soil groups represented in the paha. Further study may reveal soils present of other great soil groups.

9. Considerable physical differences are evident between soils of the paha and soils developed from blanket loess. The soils of the paha exhibit the same general trends of increasing volume weight, decreasing aeration and total porosity, and decreasing permeability with depth as do the soils from blanket loess. However, they exhibit these tendencies in an irregular manner.

10. Soils of the paha contain amounts of available phosphorus and potassium similar to the adjacent glacial soils, and lower than the loess soils south of the Iowan glacial drift plain.

11. The soil forming factor primarily responsible for most of the differences between soils on the paha and those adjacent to the paha is parent material, with vegetation secondary.

12. Soils developed from loess parent material should be recognized on the Iowan glacial drift. The soils of the paha appear to differ from those soils developed from loess that are currently established and mapped in the state. Therefore, new series or series established elsewhere should be used to designate soils of the paha.

13. More detailed study is necessary to furnish the scientific data necessary for correct evaluation of the soils on the paha and their proper classification.

REFERENCES

1. Aandahl, A.R. and R.W. Simonson. Soil survey of Tama County, Iowa. U.S. Bur. Pl. Ind., Div. Soil Surv., Report 22, Ser. 1938, published February, 1950.
2. Alden, W.D. and M.M. Leighton. The Iowan Drift, a review of evidences of the Iowan stage of glaciation. Iowa Geol. Surv. Report. 26:150-153. 1915.
3. Arey, M.F. Geology of Butler County. Iowa Geol. Surv. Report. 20:1-59. 1909.
4. _____. Geology of Grundy County. Iowa Geol. Surv. Report. 20:61-95. 1909.
5. Arnold, J.R., and W.F. Libby. Radiocarbon dates. University of Chicago, Institute of Nuclear Studies. 1950.
6. Bagnold, J.A. The physics of blown sand and desert dunes. London, Methuen and Company, Ltd. 1941.
7. Baker, F.C. Pulmonate mollusca peculiar to the pleistocene period, particularly the loess deposits. Jour. Paleontol. 5:270-292. 1931.
8. Baver, L.D. Soil permeability in relation to noncapillary porosity. Soil Sci. Soc. Amer. Proc. 3:52-54. 1938.
9. Black, C.A. Laboratory methods of soil investigation. Soil fertility. Dept. Agron. Iowa State College, Ames. 1949.
10. Bray, R.H. and E.E. DeTurk. Chemical aspects of some Illinois soils as related to their genesis and morphology. Second Internatl. Cong. Soil Sci. Proc. Commission. 5:118-131. (Moscow) 1930.
11. Brown, P.E. The soils of Iowa. Iowa Agr. Exp. Sta. Special Rept. No. 3. 1936.
12. Calvin, Samuel. Geology of Jones County. Iowa Geol. Surv. Rept. 5:35-114. 1895.
13. _____. Geology of Johnson County. Iowa Geol. Surv. Rept. 7:33-116. 1896.
14. _____. Geology of Delaware County. Iowa Geol. Surv. Rept. 8:119-199. 1897.
15. Chamberlin, T.C. A supplemental hypothesis respecting the origin of the loess of the Mississippi Valley. Jour. Geol. 5:795-802. 1897.
16. Flint, R.F. Glacial geology and the Pleistocene epoch. New York, John Wiley and Sons, Inc. 1947.
17. Hobbs, W.H. Loess, pebble bands and boulders from glacial outwash of Greenland continental glaciers. Jour. Geol. 39:381-385. 1931.
18. Humbert, R. P. and C. E. Marshall. Mineralogical and chemical studies of soil formation from acid and basic igneous rocks in Missouri. University of Missouri Res. Bull. 359. 1943.
19. Hunter, R. Physical properties of some loess-derived prairie soils of southeastern Iowa. Unpubl. M.S. thesis. Iowa State Coll. Libr. Ames. 1950.
20. Hutton, C.E. The morphology and genesis of prairie soils developed from Peorian loess in southwestern Iowa. Unpubl. Ph.D. thesis. Iowa State College Library, Ames. 1948.
21. Kay, G.F. and E.T. Apfel. The pre-Illinoian Plesitocene geology of Iowa. Iowa Geol. Surv. Rept. 34:1-304. 1928.

22. _____ and J.B. Graham. The Illinoian and post-Illinoian Pleistocene geology of Iowa. Iowa Geol. Surv. Rept. 38:1-263. 1941.
23. _____ and M.M. Leighton. The Eldoran epoch of the Pleistocene period. Geol. Soc. of Amer. Bull. 44:669-673. 1933.
24. Kilmer, V.J. and L.T. Alexander. Methods of making mechanical analyses of soils. Soil Sci. 68:15-24. 1949.
25. Leighton, M.M. The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley. Jour. Geol. 38:45-53. 1931.
26. Leverett, Frank. The Peorian soil and weathered zone Toronto formation?. Jour. Geol. 6:244-249. 1898.
27. McGee, W.J. The Pleistocene history of northeastern Iowa. U.S. Geol. Surv. 11th Ann. Rept. Part 1:199-577. 1890.
28. Moss, H.C. Some field and laboratory studies of soil drifting in Saskatchewan. Scientific Agric. 15:665-679. 1935.
29. Nelson, W.R. and L.D. Baver. Movement of water through soils in relation to nature of pores. Soil Sci. Soc. Amer. Proc. 5:69-76. 1940.
30. Norton, W.H. Geology of Linn County. Iowa Geol. Surv. Rept. 4: 177-184. 1894.
31. _____. Geology of Scott County. Iowa Geol. Surv. Rept. 9:395-399. 1898.
32. _____. Geology of Cedar County. Iowa Geol. Surv. Rept. 11:279-396. 1900.
33. _____. Geology of Bremer County. Iowa Geol. Surv. Rept. 16:321-405. 1905.
34. Olmstead, L.B., L.T. Alexander, and H.B. Middleton. A pipette method of mechanical analysis of soils based on an improved dispersion procedure. U.S. Dept. Agric. Tech. Bull. 170. 1930.
35. Riecken, F.F., W.H. Allaway, and Guy D. Smith. Some soil classification and mapping problems in the Wisconsin drift area of Iowa. Soil Sci. Soc. Amer. Proc. 12:432-440. 1947.
36. _____ and Guy D. Smith. Principal upland soils of Iowa. Joint paper, Iowa Agric. Exp. Sta. and Div. Soil Surv., Bur. Pl. Ind., Soils and Agric. Engr., U.S. Dept. Agric. 1949.
37. Ruhe, R.V. Reclassification and correlation of the glacial drifts of northwestern Iowa and adjacent areas. Unpubl. Ph.D. thesis. University of Iowa Library, Iowa City. 1950.
37a. _____, and W.H. Scholtes. Radiocarbon dates in central Iowa. Jour. Geol. 63:82-92. 1955.
38. Savage, T.E. Geology of Benton County. Iowa Geol. Surv. Rept. 15: 125-225. 1904.
39. _____. Geology of Fayette County. Iowa Geol. Surv. Rept. 15:433-546. 1904.
40. Scholtes, W.H. and Guy D. Smith. Some observations of the paha of northeast Iowa. Proc. Iowa Acad. Sci. 57:283-291. 1950.
41. Shimek, B. The loess of Natchez, Mississippi. Amer. Geologist. 30:279-299. 1902.
42. _____. The loess of the paha and river ridge. Proc. Iowa Acad. Sci. 15:117-136. 1908.

43. _____. The significance of Pleistocene mollusks. Science 37:501-509. 1913.
44. _____. Land shells as indicators of ecological conditions. Ecology. 11:673-686. 1930.
45. _____. Ecological conditions during loess deposition. Iowa Studies in Natural History. 14:38-59. 1931.
46. Simonson, R.W., T.H. Benton, and H.R. Meldrum. Iowa Agric. Exp. Sta. Soil Survey of Franklin County Iowa. No. 79. 1940.
47. Smith, Guy D. Illinois loess. Illinois Agric. Exp. Sta. Bull. 490. 1942.
48. _____, W.H. Allaway, and F.F. Riecken. Prairie soils of the upper Mississippi Valley. Advances in Agronomy 2:157-205. 1950.
49. Smith, R.M. and D.R. Browning. Some suggested laboratory standards of subsoil permeability. Soil Sci. Soc. Amer. Proc. 1:21-26. 1946.
50. Stevenson, W.H. and P.E. Brown. Iowa Agricultural Experiment Station. Soil survey of Bremer County, Iowa. No. 1. 1917.
51. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Clinton County, Iowa. No. 8. 1918.
52. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Linn County, Iowa. No. 17. 1920.
53. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Cedar County, Iowa. No. 28. 1922.
54. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Fayette County, Iowa. No. 30. 1923.
55. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Benton County, Iowa. No. 46. 1927.
56. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Grundy County, Iowa. No. 47. 1927.
57. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Floyd County, Iowa. No. 48. 1927.
58. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Winneshiek County, Iowa. No. 52. 1928.
59. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Delaware County, Iowa. No. 56. 1929.
60. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Jones County, Iowa. No. 57. 1929.
61. _____, _____. Iowa Agricultural Experiment Station. Soil survey of Butler County, Iowa. No. 70. 1933.
62. Thorp, James and Guy D. Smith. Higher categories of soil classification: order, suborder and Great Soil Groups. Soil Sci. 67:117-126. 1949.
63. Todd, J.E. Richtofen's theory of the loess in the light of the deposits of the Missouri. Proc. Amer. Assoc. Advt. Sci. 27:3-10. 1879.
64. Tyner, E.H. The use of sodium metaphosphate for dispersion of soils for mechanical analysis. Soil Sci. Soc. Amer. Proc. 4:103-113. 1939.
65. Udden, J.A. Geology of Clinton County. Iowa Geol. Surv. Rept. 15: 369-431. 1904.

66. Ulrich, R. Some physical and chemical properties of Planosol and Weisenboden soil series as related to loess thickness and distribution. Unpubl. Ph.D. thesis. Iowa State College Library, Ames. 1949.
67. United States Department of Agriculture Yearbook. Soils and Men. pp. 1056-1057. 1938.
68. United States Department of Agriculture Yearbook. Climate and Man. pp. 862-872. 1941.
69. United States Department of Agriculture Research Report. Characteristics of the Gray Brown Podzolic and related soils derived from loess in the upper Mississippi Valley. 1945.
70. Williams, I.A. Geology of Franklin County. Iowa Geol. Surv. Rept. 16:453-507. 1905.
71. Wilson, H. A., F. F. Riecken, and G. M. Browning. Soil profile characteristics in relation to drainage and level terracing. Soil Sci. Soc. Amer. Proc. 1:110-118. 1946.
72. Woodruff, C.M. Linear changes in the Shelby loam profile as a function of soil moisture. Soil Sci. Soc. Amer. Proc. 1:65-70. 1936.

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INHERITANCE OF RESISTANCE TO TWO RACES OF CROWN RUST IN OATS[1]

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Recent changes in the prevalence of certain physiologic races of Puccinia coronata avenae serve to re-emphasize the dynamic nature of breeding for resistance to crown rust of oats. The production of new races and biotypes within races through hybridization and mutation makes the task of maintaining effective resistance to prevalent races a difficult one. Breeding for resistance to crown rust generally has involved a search of the world oat collection or other sources for types resistant to prevalent races of the organism and the subsequent incorporation of this resistance into agronomically acceptable varieties. The use of Victoria and Bond oats in past years and the current use of the Landhafer and Santa Fe varieties are outstanding examples of this practice.

Fundamental studies of the inheritance of resistance to the crown rust organism have been somewhat limited. The host-parasite relationships involved in resistance represent the expression of a delicate balance between genotypes of both the host and pathogen. It might be expected, therefore, that opportunity for complex gene interaction would occur, with different genes or a combination of different genes determining resistance to various forms of crown rust.

The purpose of this investigation was to study the inheritance of resistance of several oat varieties to specific races of the crown rust organism and to associate the findings with previous work involving other varieties commonly used by oat breeders in breeding for crown rust resistance. A summary of previous genetic interpretations governing resistance and susceptibility to crown rust, races of the organism used, sources of resistance, and the respective references is given in Table 1.

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Table 1. Summary of genetic interpretations governing resistance and susceptibility to crown rust, races used, sources of resistance and references.

Source	Crown rust race No.	Genetic interpretation of factors governing resistance	References
Algerian-Calcutta 89	33	Single dominant factor	4
Anthony-Bond x Boone	57	Two independent dominant factors	7
Bondvic	101	Two independent dominant factors	19
Bond	1, 7, 46 and composites	Single dominant factor	9, 20
	1, 3, 6	Two dominant complementary factors	1, 8, 9, 11, 21
Clinton	57	Inhibitor factor to Klein 69b	7
	1	Single recessive factor	19
Fulghum	33	Inhibitor factor to sunrise 23	4
Iowa 444	1, 7, 46	Inhibitor factor to Bond	20
Klein 69b	57	Single dominant factor	7
Landhafer	1, 3, 4, 5, 6, 33, 57, 68	Single dominant factor	7, 10, 12, 19
	1, 101	Single recessive factor	19
Red Rustproof	33	Single dominant factor	2, 3, 4, 21
	Unknown		
Richland-Fulghum	1	Two complementary inhibitor factors to Bond	1
Santa Fe	1, 45, 57	Single dominant factor	7, 12
	45	Single dominant factor and two complementary factors	14, 18
	1	Single dominant factor and one of two complementary factors from Bond	12
	45, 101	Two dominant linked factor pairs with 23 per cent recombination	19
Sunrise 23	33	Single dominant factor	4
Trispernia	57, 1, 101	Single dominant factor	7, 19
Ukraine	Biotype of race 1	Two dominant complementary factors	21
	57	Two dominant linked factors with 23 per cent recombination	7
Victoria	1, 45, 57	Single dominant factor	1, 7, 12, 17

EXPERIMENTAL PROCEDURE

This investigation consisted of the evaluation for crown rust reaction of all possible hybrid combinations among three parental varieties. Crosses were tested in both the F_2 and F_3 generations with races* 57 and 109 of the crown rust organism. The crosses studied were: Cross No.1, Clinton** (C.I.5011) x Ukraine (C.I.3259), Cross No.2, Santa Fe (C.I. 4518) x Clinton, and Cross No. 3, Ukraine x Santa Fe.

F_2 seeds of crosses 2 and 3 were spaced at one foot intervals in the field at Ames, Iowa, in the spring of 1950. The other cross, Clinton x Ukraine, was made in the winter of 1950 in the greenhouse at Ames and the seed grown at Aberdeen, Idaho, in the spring of 1951 for maximum seed increase. F_2 seeds from this cross were planted in the greenhouse in flats fitted with one-inch paper bands and filled with sterilized soil. The F_2 seedlings were tested for crown rust reaction in the spring of 1952 and later transplanted to the field at Ames.

Approximately 200 progenies from each F_2 plant were tested to race 57 of crown rust in the greenhouse during the fall and winter of 1952-53 and another 200 progenies from the same plant tested to race 109. For each of the three crosses approximately 100 F_2 plants were tested to each of the two races. The inoculum of race 57 was supplied by Dr. E.L. Sharp, Ames, Iowa, as lyophilized spores from the same inoculum used by Finkner (7). The senior author isolated race 109 from an infected leaf of Ukraine oats supplied by Dr. M.D. Simons, U.S.D A., Ames, Iowa. Both races were purified by repeated single pustule isolations and increased on the Markton variety.

Plants were inoculated in the first-leaf stage of growth using the spore-talc method as described by Finkner et al. (5). A mixture of 1 part rust spores to 50 parts talc was adequate for obtaining heavy infection. All plants were placed in a humidity chamber for a period of 24 hours following inoculation, and rust reactions were recorded 12 to 14 days later. Seedling reactions were determined in accordance with the scale described by Murphy (15) and illustrated by Finkner (7). The immune- and zero-reaction types were placed in separate classes in this study.

EXPERIMENTAL RESULTS

The results from inheritance studies with each of the three crosses will be presented separately.

Cross 1: Clinton x Ukraine

The cross Clinton x Ukraine involved the extremes in rust reaction to both races used in this study. Ukraine was fully susceptible to race 109

*Race number is dependent upon the set of differential varieties used. Races classified as 57 and 109 by the old set are designated 202 and 228, respectively, with the new set of differentials. The races will be referred to as 57 and 109 in this presentation.

**The seed of Clinton used in this investigation was from a single panicle selection of the original Clinton variety made by Dr. D.D. Morey in 1946.

and fully immune to race 57, while Clinton showed a resistant 0-type infection with race 109 and a fully susceptible reaction to race 57.

Classification of the F_2 plants in this cross was based on their progeny behavior in the F_3 generation with one-half of the progeny from each F_2 plant tested to each of the two races. The following segregation was obtained from inoculations with race 109: 8 bred true for resistance, 51 segregated, and 49 bred true for susceptibility. The segregating group was further separated into two classes, according to the preponderance of resistant and susceptible plants in each progeny. One class contained more resistant than susceptible plants in its progeny while the reverse was true for the other class. The number of plants observed in the two segregating classes was 15 and 36, respectively.

The observed frequencies suggested the presence of a dominant inhibitor factor pair (MM) in Ukraine which was epistatic to the dominant factor pair (AA) for resistance from Clinton. On the basis of this assumption the expected and observed numbers of the different genotypes are shown in Table 2. For the population of 108 plants classified, 6.75 should have been true breeding resistant types, 13,50 should segregate more resistant than susceptible plants, 40.50 should segregate more susceptible than resistant types, while the remaining 47.25 should have bred true for susceptibility. The numbers observed in the four classes were 8, 15, 36, and 49 respectively. A chi-square value of 1.55 and a corresponding P value of 0.5-0.7 was obtained for these numbers which indicated a satisfactory fit to the hypothesis.

Table 2. Expected and observed frequencies of phenotypic and genotypic classes from the cross Clinton x Ukraine for reaction to race 109 of crown rust.

Generation	Phenotype	Genotype	Breeding Behavior	Exp. per cent	Exp. No.	Obs. No.
♀ Parent (Clinton)	Resistant	mm AA	Resistant			
♂ Parent (Ukraine)	Susceptible	MM aa	Susceptible			
F_1	Do.	Mm Aa	Segregate			
F_2	Do.	MM AA	Susceptible	6.25		
	Do.	MM Aa	Do.	12.50		
	Do.	MM aa	Do.	6.25	47.2	49
	Do.	Mm aa	Do.	12.50		
	Do.	mm aa	Do.	6.25		
	Do.	Mm AA*	Segregate	12.50		
	Do.	Mm Aa**	Do.	25.00	40.5	36
	Resistant	mm Aa***	Do.	12.50	13.5	15
	Do.	mm AA	Resistant	6.25	6.8	8

* Segregating 3 susceptible: 1 resistant
** Segregating 13 susceptible; 3 resistant
***Segregating 3 resistant; 1 susceptible
Chi square (3 d.f.) = 1.55 P = 0.50 - 0.70

From the segregating portion of the F_2 population a ratio of 34.4 per cent resistant to 65.6 per cent susceptible was expected in the F_3 generation. The classification of 9,309 F_3 plants showed 3,291 resistant and 6,018 susceptible types in comparison with the expected numbers of 3,200 resistant and 6,109 susceptible. The chi-square value for testing the observed numbers was 3.91 which barely exceeded the 5 per cent level of probability. This would not seem to constitute conclusive evidence against the hypothesis, however, in view of the closeness to an acceptable fit and the possibility of some misclassification of plants that bordered between a resistant and a susceptible reaction.

To explain the results from testing the F_2 plants of cross 1 with race 57 of crown rust, the hypothesis was proposed that the parents differed by a single dominant factor pair determining resistance and susceptibility. It was assumed that the Ukraine parent possessed a single dominant factor (MM) for resistance and the recessive alleles (mm) were carried by the Clinton parent. The F_2 genotypes and the expected and observed numbers are given in Table 3. Based on the progeny test of 117 F_2 plants the observed segregation gave a satisfactory fit to a 1 resistant:2 segregating:1 susceptible ratio. As with race 109 the classifications in F_3 of the segregating section of the F_2 did not follow the expected distribution; but, again, this may have been the result of possible misclassification of some plants bordering between resistance and susceptibility.

An examination of the data from the segregating populations of cross 1 for reaction to races 57 and 109 indicated a definite association of reaction to the two races. The dominant gene (MM) in Ukraine, which inhibited resistance to race 109, appeared also to condition resistance to race 57. Furthermore, the dominant gene (AA) in Clinton, which governed resistance to race 109 in the absence of the Ukraine gene (UU), apparently had no effect on the reaction to race 57. The expected and observed frequencies based on this hypothesis are presented in Table 4 together with the chi-square value for goodness of fit. A satisfactory agreement with the hypothesis is indicated.

Cross 2: Santa Fe x Clinton

The Santa Fe parent generally gave a 0 reaction from inoculations with either race 57 or 109, although a 1-type reaction was observed under some conditions. Clinton was fully susceptible to race 57 and gave a 0 reaction to race 109.

Progeny from 127 F_2 plants of cross 2 were classified for reaction to race 57 and the following segregation obtained: 50 bred true for the Santa Fe type resistance, 60 segregated into parental types and 17 bred true for susceptibility. The numbers observed suggested that linkage was involved in the action of the genes governing reaction to crown rust in this cross. By assuming that Santa Fe possessed two linked factors determining resistance ($M_1M_1\ U_1U_1$), each dominant and each capable of producing the Santa Fe type resistance, the linkage intensity was estimated from the fully classified F_2 data. It should be pointed out that not all crossover types could be distinguished from the non-crossover types by their reaction type even with progeny tests. The best estimate of linkage, therefore, was obtainable from the three identifiable F_2 classes, i.e., resistant, segregating, and susceptible.

Table 3. Observed and expected frequencies of phenotypic and genotypic classes from the cross Clinton x Ukraine for reaction to race 57 of crown rust.

Generation	Phenotype	Genotype	Breeding behavior	Exp. per cent	Exp. No.	Obs. No.
♀ Parent (Clinton)	Susceptible	mm	Susceptible			
♂ Parent (Ukraine)	Resistant	MM	Resistant			
F_1	Resistant	Mm	Segregate			
F_2	Resistant	MM	Resistant	25	29.25	32
F_2	Resistant	Mm	Segregate	50	58.50	60
F_2	Susceptible	mm	Susceptible	25	29.25	25

Chi square (2 d.f.) = 0.92 P = 0.50 - 0.70

Table 4. Expected and observed frequencies of different associations of genotypes occurring in the cross Clinton x Ukraine when tested to races 57 and 109 of crown rust.

F_2 Genotype	Reaction to race 57	Reaction to race 109	Exp. per cent	Exp. No.	Obs. No.
MM AA	Resistant	Susceptible	25.00	24.5	25
MM Aa	Resistant	Susceptible			
MM aa	Resistant	Susceptible			
Mm AA	Segregating	Segregating	37.50	36.8	31
Mm Aa	Segregating	Segregating			
Mm aa	Segregating	Susceptible	12.50	12.3	19
mm AA	Susceptible	Resistant	6.25	6.1	7
mm Aa	Susceptible	Segregating	12.50	12.2	13
mm aa	Susceptible	Susceptible	6.25	6.1	3

Chi square (5 d.f.) = 6.39 P = 0.20 - 0.30

Table 5. Expected and observed frequencies of phenotypic and genotypic classes from the cross Santa Fe x Clinton for reaction to race 57 of crown rust.

Generation	Phenotype	Genotype	Breeding behavior	Exp. per cent	Exp. No.	Obs. No.
♀Parent (Santa Fe)	Resistant	$\frac{M_1U_1^*}{M_1U_1}$	Resistant			
♂Parent (Clinton)	Susceptible	$\frac{m\ u}{m\ u}$	Susceptible			
F_1	Resistant	$\frac{M_1U_1}{m\ u}$	Segregate			
F_2	Do.	$\frac{M_1U_1}{M_1U_1}$	Resistant	12.67		
	Do.	$\frac{M_1U_1}{M_1u}$	Do.	10.26		
	Do.	$\frac{M_1u}{M_1u}$	Do.	2.07	47.4	50
	Do.	$\frac{M_1U_1}{m\ U_1}$	Do.	10.26		
	Do.	$\frac{m\ U_1}{m\ U_1}$	Do.	2.07		
	Do.	$\frac{M_1U_1}{m\ u}$	Segregate	25.34		
	Do.	$\frac{M_1u}{m\ U_1}$	Do.	4.14		
	Do.	$\frac{M_1u}{m\ u}$	Do.	10.26	63.5	60
	Do.	$\frac{m\ U_1}{m\ u}$	Do.	10.26		
	Susceptible	$\frac{m\ u}{m\ u}$	Susceptible	12.67	16.1	17

*Recombination value for linked Santa Fe genes = 28.8 per cent.
Chi square (1 d.f.) = 0.38 P = 0.50 - 0.70

Table 7. Expected and observed frequencies of different associations of genotypes from the cross Santa Fe x Clinton when tested for reaction to races 57 and 109 of crown rust.

F_2 Genotype	Reaction to race 57	Reaction to race 109	Exp. Per cent	Exp. No.	Obs. No.
$M_1M_1U_1U_1AA$	Resistant	Resistant	3.17		
$M_1m\ U_1U_1AA$	Do.	Do.	2.56		
$M_1M_1U_1u\ AA$	Do.	Do.	2.56		
$M_1M_1U_1U_1Aa$	Do.	Do.	6.34		
$M_1m\ U_1U_1Aa$	Do.	Do.	5.12		
$M_1M_1U_1u\ Aa$	Do.	Do.	5.12		
$M_1M_1U_1U_1aa$	Do.	Do.	3.17	37.70	37
$M_1M_1U_1u\ aa$	Do.	Do.	2.56		
$M_1m\ U_1U_1aa$	Do.	Do.	2.56		
$M_1M_1uu\ AA$	Do.	Do.	0.52		
$M_1M_1uu\ Aa$	Do.	Do.	1.04		
$M_1M_1uu\ aa$	Do.	Do.	0.52		
$mm\ U_1U_1AA$	Do.	Do.	0.52		
$mm\ U_1U_1Aa$	Do.	Do.	1.04		
$mm\ U_1U_1aa$	Do.	Do.	0.52		
$M_1m\ U_1u\ AA$	Segregate	Do.	7.38		
$M_1m\ uu\ AA$	Do.	Do.	2.56	12.62	20
$mm\ U_1u\ AA$	Do.	Do.	2.56		
$M_1m\ U_1u\ Aa$	Do.	Segregate	14.76		
$M_1m\ U_1u\ aa$	Do.	Do.	7.38		
$M_1m\ uu\ Aa$	Do.	Do.	5.12	37.88	31
$M_1m\ uu\ aa$	Do.	Do.	2.56		
$mm\ U_1u\ Aa$	Do.	Do.	5.12		
$mm\ U_1u\ aa$	Do.	Do.	2.56		
$mm\ uu\ Aa$	Susceptible	Do.	6.34	6.40	9
$mm\ uu\ AA$	Do.	Resistant	3.17	3.20	2
$mm\ uu\ aa$	Do.	Susceptible	3.17	3.20	2

Chi square (5 d.f.) = 7.54 P = 0.10-0.20

the F_3 population tested no fully susceptible plants were observed, indicating that the Ukraine factor (MM) was allelic to one of the linked Santa Fe factors ($M_1M_1\ U_1U_1$). The Ukraine factor for resistance also appeared to be dominant and epistatic to the Santa Fe factors. Thus, whenever the Ukraine gene was present in a genotype it conditioned immunity to race 57. The expected behavior of the progenies of F_2 plants based on these assumptions is shown in Table 8. Selections breeding true for the Ukraine type of resistance should constitute 25 per cent of the population, 50 per cent should segregate for the Ukraine and Santa Fe types of resistance,

Table 8. Expected and observed frequencies of phenotypic and genotypic classes from the cross Ukraine x Santa Fe for reaction to race 57 of crown rust.

Generation	Phenotype	Genotype	Breeding behavior	Exp. per cent	Exp. No.	Obs. No.
♀ Parent (Ukraine)	Immune	MM uu	Immune			
♂ Parent (Santa Fe)	0 type	$\frac{M_1U_1}{M_1U_1}$[1]	Resistant			
F_1	Immune	$\frac{M\ u}{M_1U_1}$	Segregate			
F_2	0 type	$\frac{M_1U_1}{M_1U_1}$	Resistant			
	Do.	$\frac{M_1u}{M_1U_1}$	Do.	25	22.75	21
	Do.	$\frac{M_1u}{M_1u}$	Do.			
	Immune	$\frac{M\ U_1}{M_1U_1}$	Segregate parental types			
	Do.	$\frac{M\ u}{M_1U_1}$	Do.	50	45.50	48
	Do.	$\frac{M\ u}{M_1u}$	Do.			
	Do.	$\frac{M\ U_1}{M\ U_1}$	Immune			
	Do.	$\frac{M\ u}{M\ U_1}$	Do.	25	22.75	22
	Do.	$\frac{M\ u}{M\ u}$	Do.			

[1]Recombination value for linked Santa Fe genes = 28.8 per cent.
Chi square (2 d.f.) = 0.30 P = 0.80-0.90

while the remaining 25 per cent should be true breeding, Santa Fe resistance types. The expected numbers from the population of 91 plants in accordance with this hypothesis were 22.75 with the Ukraine resistance, 45.50 segregating and 22.75 with the Santa Fe resistance. Observed numbers for the three classes were 21, 48, and 22, respectively, which is in good agreement with the hypothesis.

Table 9. Expected and observed frequencies of phenotypic and genotypic classes from the cross Ukraine x Santa Fe for reaction to race 109 of crown rust.

Generation	Phenotype	Genotype	Breeding behavior	Exp. per cent	Exp. No.	Obs. No.
♀ Parent (Ukraine)	Susceptible	MM uu	Susceptible			
♂ Parent (Santa Fe)	0 type	$\frac{M_1U_1}{M_1U_1}$ [1]	Resistant			
F_1	0 type	$\frac{M_1U_1}{M\ u}$	Segregate			
F_2	Do.	$\frac{M_1U_1}{M_1U_1}$	Resistant	12.67		
	Do.	$\frac{M_1U_1}{M\ U_1}$	Do.	10.26		
	Do.	$\frac{M_1U_1}{M_1u}$	Do.	10.26	36.96	27
	Do.	$\frac{M_1u}{M_1u}$	Do.	2.07		
	Do.	$\frac{M\ U_1}{M\ U_1}$	Do.	2.07		
	Resistant	$\frac{M_1u}{M\ U_1}$	Segregate	29.48		
	Susceptible	$\frac{M\ U_1}{M\ u}$	Do.	10.26	49.50	59
	Do.	$\frac{M\ u}{M_1u}$	Do.	10.26		
	Do.	$\frac{M\ u}{M\ u}$	Susceptible	12.67	12.54	13

1/ Recombination value for linked Santa Fe genes = 28.8 per cent.
Chi square (2 d.f.) = 4.52 P = 0.10-0.20

Accurate classification for type of resistance could not be made for the portion of the population which should segregate in F_3 since the Ukraine gene (M) is only partially dominant to the M_1 gene or partially epistatic to the U_1 gene from Santa Fe.

The F_2 plants, when fully classified for reaction to race 109, indicated that the Ukraine gene (MM) was dominant to the Santa Fe gene (M_1M_1) and conditioned susceptibility to this race in the absence of the other dominant linked Santa Fe gene (U_1U_1). The U_1U_1 gene from Santa Fe was epistatic to the MM gene of Ukraine if the Santa Fe gene was in the homozygous condition or if the M gene was in the heterozygous condition.

Table 10. Expected and observed frequencies of different associations of genotype occurring in the cross Ukraine x Santa Fe when tested for reaction to races 57 and 109 of crown rust.

F_2 Genotype	Reaction to race 57	Reaction to race 109	Exp. per cent	Exp. No.	Obs. No.
$M_1M_1U_1U_1$	Resistant	Resistant			
$M_1M_1U_1u$	Do.	Do.	25.00	22.25	20
M_1M_1uu	Do.	Do.			
M M1U1U1	Segregate	Do.	10.26	9.13	5
M M_1U_1u	Do.	Segregate	39.74	35.37	43
M M_1 uu	Do.	Do.			
M M U_1u	Immune	Do.	10.26	9.13	10
M M U_1U_1	Do.	Resistant	2.07	1.84	1
M M uu	Do.	Susceptible	12.67	11.28	10

Chi square (5 d.f.) = 4.35 P = 0.30-0.50

A dosage effect was apparent when the gene MM was in the homozygous condition and U_1 was in a heterozygous condition. This genotype (MMU_1u_1) was susceptible to race 109 in the F_2 generation and segregated three susceptible to one resistant type in the F_3. It also was immune to race 57 and could be identified in that manner.

Based on the assumptions presented above, together with the premise of 28.8 per cent crossing over between the linked Santa Fe genes, the expected segregations and observed numbers are given in Table 9. From the classification of progeny from 99 F_2 plants the expected numbers were 39.96 resistant, 49.50 segregating and 12.54 susceptible. The numbers observed were 27 resistant, 59 segregating and 13 susceptible which gave a probability of 0.1-0.2 in support of the hypothesis. Because of the complicated gene actions involved, critical interpretation of classifications within the segregating portion of the population could not be made. Plants that were classified as breeding true for the Santa Fe resistance to race 57 also gave a 0 reaction to race 109. Plants classified in the F_2 as immune to race 57 were susceptible, resistant, or segregating to race 109. The expected and observed frequencies of different associations of reaction to races 57 and 109 are shown in Table 10.

Progenies of two F_2 plants among the 91 classified for reaction to both races of rust, could not be placed in any of the combined classes in Table 10. They were classified as having the Santa Fe type of resistance to race 57 and as segregating for reaction to race 109. This discrepancy probably was due either to misclassification or was a result of two contaminate F_2 seeds. By omitting the two questionable plants from the analysis the chi-square value for the association of reaction to the two races indicated a good fit to the proposed hypothesis.

DISCUSSION

This study was designed with the assumption that the inheritance of crown rust reaction in oats was Mendelian in nature and that the parents involved were homozygous for their particular type of crown rust reaction. The results obtained indicate that these assumptions basically were correct. Some selections within a particular parental variety, however, appeared to have only one gene for resistance while other selections from the same parent apparently possessed two genes determining resistance. The exact origin of some of the parental varieties is not definitely known, but it seems likely that seed of a particular parent used in making some crosses was not always descendent from a single homozygous plant. Therefore, although selection for crown rust reaction had been practiced, it is unlikely that all plants of some of the parental varieties were of identical genotype.

The parents used in this investigation currently are in common use by oat breeders and thus are particularly well suited for studying the genetic relationships of different sources of resistance to specific races of crown rust. Clinton and Ukraine exhibit directly opposite reaction types to the two races of rust used, while Santa Fe is resistant to both races.

Clinton was found to possess a single dominant gene determining resistance to race 109. It was assumed that Clinton carried the Bond type of resistance, which several investigators have found to be governed by a single dominant factor, while others have proposed that two dominant complementary factors determine this type of resistance. The results obtained in this study and those reported by other workers for the Bond genes generally are not directly comparable since different races of crown rust were used in most instances and different genic background from different parents used may result in varying gene action. The results from all crosses with Clinton indicated that Clinton possesses only the recessive alleles to factors for resistance to race 57.

Ukraine was classified as immune to race 57, and the data indicate that this reaction was controlled by a single gene pair (MM). Finkner (7) reported that the reaction of Ukraine to race 57 was determined by two factor pairs (MM UU) and that these genes were linked with a recombination value of 23 per cent. Apparently the Ukraine parent used in this investigation carried only one of the two linked genes for resistance in Ukraine reported by Finkner. This easily could happen as all selections possessing either the factors MM, UU, or MM UU should be resistant and appear homozygous for rust reaction. The single factor MM was assumed to be allelic to one of the two linked Santa Fe factors (designated M_1M_1) for resistance.

When Ukraine was tested to race 109, a fully susceptible reaction was obtained. The same gene (MM) which determined resistance to race 57 appeared to govern susceptibility to race 109. A possible alternative explanation would be that the gene for resistance to race 57 and the gene for susceptibility to race 109 are very closely linked and that no crossover types were found in this investigation. Finkner (6, p. 108) also found association between the reaction of Ukraine to race 57 and to a mixture of races to which Ukraine was susceptible. He stated:

> The data in table 25 indicated the Ukraine type of resistance to race 57 is associated with susceptibility to the race which attacks Ukraine. The association was very close but not absolute if the phenotypic reaction was a correct measure of the genotype. This indicated that the factor pair conditioning the Santa Fe type of resistance to race 57 may not be allelic to one of the two linked factor pairs for resistance to race 57 from Ukraine, but instead was closely linked to one of the Ukraine factors. If this were the case one crossover type would be expected to be fully susceptible to race 57.

In the investigation reported here this association was found to be absolute and no crossover types were found. This discrepancy may be due to different races tested as Finkner used a mixture of races to which Ukraine was susceptible and not a single purified race.

Santa Fe gave a 0 type reaction to both races 57 and 109 of crown rust and was assumed to have the genotype (M_1M_1 U_1U_1), the genes being linked. A crossover value of 28.8 $\pm$ 0.8 per cent between the linked Santa Fe genes was estimated from the Santa Fe x Clinton cross. The results obtained with Santa Fe in these studies are not in agreement with the single factor hypothesis proposed by Litzenberger (12), Maung (14), or Osler (18) and in the majority of cases it is not in agreement with Finkner's interpretations (6, 7). However, Finkner (6, p. 99) found one Santa Fe parent which he believed carried two linked genes for resistance. He stated:

> Finding linked duplicate factors in some cases and a single factor in other cases in the Santa Fe variety was not surprising. Santa Fe was not a pure line and while selection had been made for rust resistance in this variety, such selection may have failed to differentiate between those plants carrying duplicate linked factors and those carrying but a single factor.

This explanation appears logical as it is known that Santa Fe was heterogeneous for reaction to certain crown rust races when first tested in the United States. The conflicting hypotheses as to the Santa Fe genotype may well be accounted for with this concept.

Maung (14) and Osler (18) proposed that the Santa Fe resistance was conditioned by three factors designated by C, D, and S. The factors C and D were considered to be independently inherited, dominant, complementary factors, and S was determined to be a different dominant factor for resistance independently inherited from C and D. Either the C and D factors together, the S factor alone, or a combination of all three factors conditioned resistance. The discrepancy between this hypothesis and the one of duplicate-linked genes, again, might be explained on the basis of different selections from the variable Santa Fe parent.

An alternative explanation of the different hypotheses may lie in the fact that the number of seedlings classified by both Maung and Osler was very small. Eachworker tested only 20 to 25 progenies from each F_2 plant and on the classifications from these small populations attributed the reactions to one, two, or three genetic factors. Mather (13, pp. 30-31) calculated the number of individuals necessary to distinguish between a 9:7 and a 3:1 segregation as 95 plants. He stated:

Thus we must grow ninety-five plants in order to distinguish between the two hypotheses with a minimum of certainty of 0.025.

Maung's data would fit the hypothesis of duplicate-linked genes with 28.8 per cent crossing over equally as well as the three factor hypothesis which he proposed. The small population tested does not, however, constitute conclusive evidence for either hypothesis.

Another explanation of the different segregations from crosses with Santa Fe may lie in the different genic constitution of the other parents involved. Maung and Osler both reported segregations from two crosses. Santa Fe was a common parent in both crosses, and the other two parents were Bond x Hajira-Joanette in one instance and Hajira-Joanette x Bond-Rainbow in the other. It seems likely that different segregations could result from using these parents as contrasted to the investigations reported herein with Clinton as the other parent.

The segregations obtained by the writers are in agreement with results presented by Simons (19). He concluded that Santa Fe possessed two duplicate-linked genes and obtained a 23 per cent recombination value between the linked genes.

The Ukraine type resistance to the races of crown rust now most prevalent in the United States is one of the most effective available to oat breeders. In a report of the reaction of oat varieties to crown rust in the 1952 Uniform Rust Nurseries by Murphy (16, p.41), Ukraine exhibited the third lowest infection with an average coefficient of 2.0. Fourteen entries in the test had coefficients of less than 5.0 and four of this group possessed the Ukraine type resistance. This represents approximately 29 per cent of the best crown rust resistant material available to oat breeders at the time of this test which contain the Ukraine genes for resistance.

Results from this investigation, however, show that while Ukraine possesses a high type of resistance to most races of crown rust now prevalent in the United States, the genes governing this resistance apparently also determine susceptibility to at least one less prevalent race. This association suggests that oat breeders probably should place less emphasis on the use of Ukraine as a crown rust resistant parent and make greater use of varieties that have not shown unfavorable associations of resistant and susceptible reactions. The varieties Santa Fe and Trispernia and certain of the Anthony-Bond x Boone selections appear to offer more stable sources of crown rust resistance than Ukraine. These varieties all were observed to have at least one gene in common with Ukraine but gave a resistant reaction to both races of crown rust used in this study. These varieties also exhibited crown rust coefficients of less than 5.0 in the 1952 Uniform Rust Nursery summary.

The value of testing adequate sized populations in studies of the inheritance of crown rust resistance cannot be over-emphasized. Conclusive genetic interpretations cannot be made from small populations, even though the work may have been very carefully carried out. At least 100 progenies from any F_2 plant should be tested if the factorial interpretation is likely to be attributed to more than one gene governing the reaction. Parents also should be crossed in all possible combinations because an hypothesis that can satisfactorily explain the results of several crosses

usually is valid even though a poor fit to the theoretical ratio may be obtained for a particular cross. The breeding behavior of a variety in diallel crosses with several varieties provides a more critical test for an hypothesis than does a mathematical test for goodness of fit for each individual cross.

In most of the crosses studied the action of the resistant gene was not completely dominant. Several of the parents exhibited a variable reaction to specific races of crown rust. In view of this a progeny test of the succeeding generation to confirm the interpretation of reactions of a given segregating generation should be considered a necessary step in crown rust inheritance studies.

SUMMARY

The mode of inheritance of reaction to races 57 and 109 of crown rust was studied in three oat crosses. Conclusions drawn from the reactions of segregating F_2 and F_3 progeny of these crosses are summarized below:

1. Resistance of the Clinton variety to race 109 was conditioned by a single dominant gene, designated (AA). Clinton exhibited only recessive alleles to factors for resistance when tested to race 57.

2. The resistance to race 57 and susceptibility to race 109 possessed by the Ukraine variety was governed by the same gene, designated (MM).

3. Two dominant linked genes determined the resistance of Santa Fe variety to both races of crown rust. The genes (M_1M_1 U_1U_1) were linked in the coupling phase with 28.8 + 0.8 per cent recombination. One of the duplicate-linked genes (M_1M_1) was allelic to the gene (MM) in Ukraine, with the Ukraine gene (MM) being dominant to the M_1M_1 gene.

REFERENCES

1. Cochran, G.W., C.O. Johnston, E.G. Heyne, and E.D. Hansing. Inheritance of reaction to smut, stem rust and crown rust in four oat crosses. Jour. Agr. Res. 70:43-61. 1945.
2. Davis, W.D. and E.T. Jones. Studies on the inheritance of resistance and susceptibility to crown rust (P. coronata Corda) in a cross between a selection of Red Rustproof (A. sterilis L.) and Scotch Potato (A. sativa L.). Welsh Jour. Agr. 2:212-221. 1926.
3. _____, _____. Further studies on the inheritance of resistance to crown rust (P. coronata Corda) in F_3 segregates of a cross between Red Rustproof (A. sterilis) and Scotch Potato oats (A. sativa). Welsh Jour. Agr. 3:232-235. 1927.
4. Dietz, S.M. and H.C. Murphy. Inheritance of resistance to Puccinia coronata avenae. Phytopath. 20:120. 1930.
5. Finkner, R.E., R.E. Atkins, and H.C. Murphy. Inoculation techniques for crown rust of oats. Agron. Jour. 45:630-631. 1953.

6. Finkner, V.C. Genetic factors governing resistance and susceptibility of oats to Puccinia coronata avenae. Eriks, and E. Henn., Race 57. Unpubl. Ph.D. thesis. Iowa State Coll. Library. 1950.
7. _____. Genetic factors governing resistance and susceptibility of oats to Puccinia coronata avenae. Eriks, and E. Henn., Race 57. Iowa Agr. Exp. Sta. Res. Bull. 411. July, 1954.
8. Hays, H.K. Breeding for resistance to crown rust, stem rust, smut, and desirable agronomic characters in crosses between Bond, Avena byzantina, and cultivated varieties of Avena sativa. Jour.
9. _____, M.B. Moore, and E.C. Stakman. Studies of inheritance in crosses between Bond, Avena byzantina, and varieties of A. sativa. Minnesota Agr. Exp. Sta. Tech. Bull. 137, 38 pp. 1939.
10. Kehr, W.R. and H.K. Hayes. Studies of inheritance in crosses between Landhafer, Avena byzantina L., and two selections of A. sativa L. Agron. Jour. 42:71-78. 1950.
11. Ko, Sianh Yin, J.H. Torrie, and J.G. Dickson. Inheritance of reaction to crown rust and stem rust and other characters in crosses between Bond, Avena byzantina, and varieties of A. sativa. Phytopath. 36:226-235. 1946.
12. Litzenberger, S.C. Inheritance of resistance to specific races of crown and stem rust, to Helminthosporium blight, and of certain agronomic characters of oats. Iowa Agr. Exp. Sta. Res. Bull. 370. pp. 454-496. 1949.
13. Mather, K. The measurement of linkage in heridity. 2nd ed. New York., John Wiley and Sons, Inc. 1951.
14. Maung, K. Inheritance of reaction to crown rust and other characters in oats. Unpubl. M.S. thesis. University of Minnesota, Minneapolis, Minn. 1950.
15. Murphy, H.C. Physiologic specialization in Puccinia coronata avenae. U.S. Dept. Agr. Tech. Bull. 433:1-9. 1935.
16. _____. Reaction of oat varieties to crown rust in the 1952 Uniform Rust Nurseries. National Oat Newsletter. 3:39-41. 1952.
17. _____, T.R. Stanton, and H. Stevens. Breeding winter oats resistant to crown rust, smut and cold. Jour. Amer. Soc. Agron. 29: 622-637. 1937.
18. Osler, R.D. and H.K. Hayes. Inheritance studies in oats with particular reference to the Santa Fe type of crown rust resistance. Agron. Jour. 45:49-53. 1953.
19. Simons, M.D. Physiologic specialization and inheritance of resistance to specific races of Puccinia coronata Corda var. avenae F. and L. Unpubl. Ph.D. thesis. Iowa State College Library, Ames, Iowa. 1952.
20. Torrie, J.H. Correlated inheritance in oats of reaction to smuts, crown rust, stem rust, and other characters. Jour. Agr. Res. 59: 783-804. 1939.
21. Weetman, L.M. Genetic studies in oats of resistance to two physiologic races of crown rust. Phytopath. 32:19. 1942.

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GERMINATION AND RESPIRATION RESPONSES OF MYROTHECIUM VERRUCARIA TO ORGANIC FUNGICIDES[1]

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The extent of economic damage by fungi is reduced either by elimination of conditions favoring their growth or, where this is not possible, by control with appropriate fungicides. Few, if any, of these compounds qualify under more than a limited number of conditions. Consequently, a considerable variety of fungal toxicants has been developed and the number continues to increase in response to problems arising from different susceptibilities among fungi, relative toxicity to higher plants or animals, and differing conditions of use. Currently, the selection of an effective fungicide is largely based on laboratory screening tests for inhibition of growth and on results in practical use. However, more efficient choice and development of improved fungicides could derive from an understanding of the mechanisms of toxic action on the metabolism of fungi.

The effects of toxic action can be measured by slide-germination tests, on seeded agar with toxicant in diffusion cells, on streaked agar plates or in broth cultures with toxicant in the media, or in related variations of these. Such results show that growth is or is not inhibited but offer no definite clue to the mechanism of action. Manometric methods applied to fungi can measure effects of toxicants on respiratory metabolism and may also reveal the type as well as the degree of inhibition.

Relatively little is known of the nature of toxicant action, but compounds similar to some of the fungicides are known to inhibit respiration and, in some cases, specific enzyme systems. Organic Hg compounds may inhibit enzymes containing an SH group by mercaptide formation (18). Since yeast carboxylase and alcohol dehydrogenase, which contain SH groups, are inhibited by quinones, it has been suggested that the similar inhibitions of spore germination of Monilia fructicola and of fermentation of Fusarium solani f. pisi were brought about by inhibition of these enzymes in the fungi (7, 8). Hoffman-Ostenhof (9), however, considered the mode of action of quinones to be complex, since they inhibit enzymes both with and witnout SH groups. The halo- and nitrophenols affect respiration and, probably, assimilation by uncoupling phosphorylation from oxidation (2, 13, 16). Although both types of phenols are described as metabolic inhibitors with similar action, the halogenated compounds are generally stronger fungicides (13, 20). Among organic sulfur compounds some derivatives of dithiocarbamic acid also have proved to be effective fungicides. Their toxicity has been attributed to the action of undissociated molecules at high concentration and dissociated molecules at low concentrations in the case of tetramethylthiuram disulfide (6) and, with disodium

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ethylenebisdithiocarbamate, to alteration of spores by addition of SH groups and to precipitation of trace metals essential to spores as metallic salts of ethylenebisdithiocarbamic acid (1). A volatile substance released by these derivatives inhibits germination of spores or conidia not otherwise in contact with the toxicants (3,19). Another interpretation may apply to tetramethylthiuram disulfide since the analogue, tetraethylthiuram disulfide (Antabuse), inhibits xanthine oxidase (15).

The present approach to the complex problem of mechanism of action is to compare the effects of representative organic fungicides or similar compounds on the germination and respiration processes of a fungus. This approach should indicate the extent to which fungicidal action is based on respiratory inhibition and perhaps also provide clues to the actual site of action.

MATERIALS AND METHODS

One of the most strongly cellulolytic species of fungi used in standard cellulose degradation tests, Myrothecium verrucaria QM460* was chosen because of its rapid and abundant growth. Sporulation took place in 4 days on starch-free filter paper laid over a modified Fries medium containing micronutrients (17). Cultures were maintained by point-inoculation to detect variants, and after 2 to 3 weeks incubation at 30°C were used to prepare spore suspensions for inoculation of spore-production cultures. The latter produced spores of uniform age within about 4 days which were used in germination tests or as inocula for mycelial cultures.

Of the nine organic fungicides** tested, actidione, p-benzoquinone (BQ), and disodium ethylenebisdithiocarbamate (DSE) were soluble in water, in most of the concentrations used. Tetrachloro-p-benzoquinone (TCBQ), 2,3-dichloro-1, 4-naphthoquinone (DCNQ), pentachlorophenol (PCP), 2,4-dinitrophenol (DNP), tetramethylthiuram disulfide (TMTD), ethyl mercury chloride (EMC), and DSE at high concentrations, were dissolved in 1.0 or 2.0 ml. of methyl cellosolve, dioxane, or ethanol before adding water to a total volume of 100 ml. Because of rapid reprecipitation, TCBQ and DCNQ were filtered through a bacterial filter and the saturated solution used. All the compounds were prepared and tested in true solution. Glassware in contact with the toxicants was chemically cleaned in a hot acid bath of concentrated sulfuric and nitric acids or in chromic acid solutions.

Spores for germination tests were harvested in water from suspension inoculated cultures (not less than 5 nor more than 14 days old, giving spore ages of 1 to 10 days). They were washed 3 times by centrifugation and then resuspended in 10 ml. of water. Counts from 11 cultures made with a Levy counting chamber showed an average of 1.8×10^8 spores/ml. Accordingly, a 0.5 ml. aliquot of spore suspension was centrifuged,

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*The two cultures of M. verrucaria QM460 were kindly provided by Dr. E. T. Reese, Philadelphia Quartermaster General Laboratories and by Dr. H. G. Shirk, Prevention of Deterioration Research Center, Washington, D.C.

**The fungicides were supplied by the following companies: Actidione, The Upjohn Co.; BQ, Fisher Scientific Co.; DCNQ, DNP, PCP, TCBQ, and TMTD, Eastman Kodak Co.; DSE and EMC, E.I. DuPont DeNemours Co., Inc.

decanted, and resuspended in 10 ml. of Mandels and Norton (10) nutrient solution at 4x concentration to give a count of about 9×10^6 spores/ml. One-half ml. of this spore suspension added to each tube of control or serial dilution of toxicant (dose ratio of 1.5 or 1.1) brought the total volume to 2.0 ml. with a final spore density of 30 to 50 per high-power field. Four drops on two slides for each dose provided 10 to 15 fields in which the total spore population, 300 to 500, gave precision to the tests. Each pair of slides was supported on U-shaped glass rods laid on wet filter paper in a petri dish. The covered petri dishes were then placed in a moist-chamber and the spores were incubated at 30°C for 4.5 to 5 hours.

The standard manometric technique for the respiration of tissue described by Umbriet, Burris, and Stauffer (21) were followed and the "direct" or two-flask method was used for measuring CO_2 evolution. All experimental work with the Warburg respirometer was done at a temperature of 30°C and pH of about 6.2. Washed spores were suspended in 10 to 15 ml. of water or nutrient (10) with a count of about $1.2\text{-}1.8 \times 10^8$ spores/ml. One ml. of this suspension was added to each Warburg flask. Toxicant in a series of dosages and water or water and solvent were added to make a total volume of 3.0 ml. Control flasks contained the same concentration of spores in nutrient and solvent as the test series. Spore suspensions in aliquots of 3.0 or 4.0 ml. in tared small tubes were centrifuged, the liquid decanted, and the spores dried at 100°C for dry weight determination.

Suspensions of mycelial pellets were produced in liquid cultures by a modification of the procedure of Darby and Goddard (4). Twenty-five ml. aliquots of medium were inoculated with spores at a concentration of 2.4 to 3.5×10^6 spores/ml. and incubated at 30°C for 24 hours on a New Brunswick rotary shaker (176 cycles per minute). The culture medium was then removed by centrifuging the mycelium in three successive washes of buffer solution. Suspensions of 10 to 12 ml. of wet mycelium in about 60 to 75 ml. of inorganic buffer provided a pipettable suspension of which 1.0 ml. was used for each flask. The medium in the Warburg flask consisted of 0.167M potassium phosphate, 0.001M magnesium sulfate, and 0.02M glucose at pH 6.2. Aliquots of 25.0 ml. of mycelial suspension, washed and filtered on tared sintered-glass crucibles, were used for dry weight determinations.

Percentage inhibition of germination or respiration was plotted against toxicant concentration on logarithm-probability coordinates. LD50 values were determined graphically from the dosage-response curves obtained according to the method of Wilcoxon and McCallan (25). The slope defined for this work is the ratio of LD30/LD70.

RESULTS

Germination and Respiration.

Germination of controls in the slide tests was rarely less than 100 per cent after 4.5- to 5-hour incubation periods. The final concentration of organic solvent, one per cent or less, delayed germination slightly, if at all. The Wilcoxon-McCallen (25) test of a 19/20 range factor applied to trials of all the toxicants examined indicated that an adequate number of spores was counted to determine the LD50 value within 2 per cent.

The rate of spore respiration increased very rapidly; the percentages of increase of each hour over the preceding one were successively about 40, 25, and 6. The rate reached a constant value during the fourth hour. Swelling of spores during the first two hours was followed by germination of a small number during the third hours. Solvent at a concentration of 1 per cent or less usually inhibited respiration 3 or 4 per cent but occasionally up to 20 per cent. Respiratory quotients of spores in nutrient averaged 0.96 for the first hour and 1.03 for the second. The average dry weight of spores was 3.25 mg. per ml. and the Q_{O_2} about 80 microliters O_2 per mg. for the first hour. The rate of increase in dry weight could not be determined accurately because insoluble salts in the nutrient were precipitated during the course of the experiment. The dry weight, therefore, was based on an aliquot of the original spore suspension in water at the same concentration as in nutrient.

As pointed out by Darby and Goddard (4), the density of inoculum affected the size, number, and condition of the mycelial pellets grown in shake-cultures. At concentrations of 2.9×10^7 or more spores per ml. the cultures remained dark with ungerminated spores, and at 3.2×10^5 or less spores/ml. the mycelial pellets were too large for pipetting. Spore concentrations of $2.4\text{-}3.5 \times 10^6$ per ml. produced colonies of 0.2-0.5 mm. diameter which were easily pipetted. Respiration rates were measured on cultures incubated 18 to 29 and 41 to 48 hours. Since maximum Q_{O_2} values were obtained from those incubated 24 to 29 hours, a 24-hour growth period was chosen for all mycelial cultures. One ml. of the final suspension contained an average dry weight of 4.14 mg. and gave an average O_2 consumption of about 250 microliters per hour, or an average Q_{O_2} of 60. Inhibition of respiration by 1 per cent solvent sometimes reached 8 to 10 per cent. Pure O_2 in the system had little or no effect on the respiration of 24-hour mycelium but increased the rates for 43- and 47-hour cultures, 23 and 15 per cent, respectively. Unlike the accelerating respiration of spores, the rate for mycelium was relatively constant over a period of two hours. The respiratory quotient for 24-hour mycelium with 0.02M glucose as the carbon source was 1.10 for seven experiments. No CO_2 was produced anaerobically.

Effects of Toxicants.

The data for comparison of the compounds are presented in Tables 1 and 2 as mean LD50 values and standard errors, rank, and mean slope values during periods of maximum sensitivity. Table 3 illustrates the changes in percentage inhibition of O_2 consumption by spores with time. Comparative inhibition of O_2 consumption and CO_2 evolution of spores is shown in Table 4. The range of inhibition of spore respiration at dosages inhibiting 99 per cent of germination and maximum percentage inhibition of respiration are also reported. Responses of spores and mycelium in respiration tests are compared as to LD50 values and time patterns of response.

Quinones. Of the three compounds tested in this group, BQ was the only one whose absolute concentration in solution was known. Although dissolved in dioxane or ethanol, TCBQ and DCNQ tended to precipitate readily on addition of water when made up at 10 ppm. Values for the filtered solution are reported as fractions of saturated solution and a

maximum concentration of 0.82 saturation was used in the trials. Satisfactory germination tests were obtained for BQ and DCNQ throughout the range of inhibition from 1 to 99 per cent but only to 80 per cent for TCBQ. Dosage-response curves of BQ for mycelial respiration were linear and inhibition of respiration reached 95-100 per cent at 75 ppm. At low concentrations, however, all three quinones stimulated O_2 consumption.

Ethyl mercury chloride. Table 1 shows that EMC was the most toxic compound in the germination and mycelial respiration tests and was second only to actidione in the spore respiration test. On the basis of LD50 values, germination was significantly more sensitive to EMC than spore respiration. However, at levels of toxicant which inhibited germination 99 per cent, spore respiration was inhibited 40-70 per cent. Inhibition of spore respiration increased with time, the LD50 averaging 25 per cent lower in the second hour than in the first. Maximum inhibition observed was about 97 per cent. Comparison of inhibition of CO_2 evolution and O_2 consumption in Table 4 shows no evidence of difference in sensitivity of these two phases of respiration to EMC. Tables 1 and 2 show that mycelial respiration was about half as sensitive as spore respiration and that the slope of the dosage response curves of the former was considerably lower. Furthermore, there was no evidence of change in inhibition of mycelial respiration with time as in the case of spores.

Table 1. Mean LD50 values and standard errors (ppm) and rank during one-hour periods of maximum sensitivity.

Toxicant	Germination		Spore Respiration		Mycelial Respiration	
EMC	1.82 ± 0.24	(1)	2.38 ± 0.40[a]	(2)	5.5 ± 1.0	(1)
Actidione	2.71 ± 0.20	(2)	1.01 ± 0.19	(1)	8.0 ± 0.2[a]	(3)
PCP	6.2 ± 0.14	(3)	9.0 ± 0.07	(3)	7.8 ± 0.9	(2)
TMTD	9.7 ± 1.1	(4)	26.3 ± 3.3	(4)	58 ± 2	(4)
BQ	10.4 ± 1.0				29.6 ± 1.9	
DSE	28.6 ± 3.0	(5)	54 ± 4[a]	(5)	>500	(6)
DNP	87 ± 8	(6)	135 ± 7	(6)	101 ± 13	(5)
DCNQ	0.25 ± 0.01[b]				0.60 ± 0.09[b]	
TCBQ	0.72 ± 0.21[b]				0.68 ± 0.06[b]	

[a]Maximum sensitivity of spores to EMC and DSE occurred in the second hour and of mycelium to actidione in the third hour.

[b]Values are in fractions of saturated solution, less than 10 p.p.m.

Actidione. The effect of actidione on germination and respiration of M. verrucaria has been reported previously (22) and only sufficient data are given here for comparison with the other toxicants. Table 1 indicates that actidione was second only to EMC in toxicity to germination. It was unique among the toxicants investigated in having greater toxicity to spore respiration than to germination on the basis of LD50 values. In fact, the LD50 for respiration (0.74 ppm) was even lower when measured over a 30-minute period than that given in Table 1. However, even at toxicant levels causing 99 per cent inhibition of germination, 20-40 per cent of spore respiration remained. Decrease in spore respiration inhibition with time was more pronounced with actidione than with any of the other toxicants. Inhibition of mycelial respiration also decreased at lower

Table 2. Mean slopes of dosage-response curves for germination and respiration during one-hour periods of maximum sensitivity (LD30/LD70).

Toxicant	Germination	Spore Respiration	Mycelial Respiration
EMC	0.85	0.32[a]	0.13
Actidione	0.88	0.08	0.24[a]
PCP	0.81	0.54	0.67
TMTD	0.80	0.37	0.40
BQ	0.81		0.48
DSE	0.80	0.45[a]	----
DNP	0.88	0.76	0.55
DCNQ	0.85		0.37
TCBQ	0.75		0.68

[a]Maximum sensitivity of spores to EMC and DSE occurred in the second hour and of mycelium to actidione in the third hour.

concentrations (below 10 ppm) but increased with time at higher levels of toxicant. Both the LD50 and slope values for inhibition of mycelial respiration were much higher than those for spore respiration. On the other hand, maximum inhibition of respiration for both was about 85 per cent. Finally, no significant difference was found in percentage inhibition of CO_2 evolution and O_2 consumption by spores.

Pentachlorophenol. The LD50 values for this toxicant did not show the marked differences among the three tests common to the other compounds (Tables 1 and 2). Inhibition of spore respiration decreased with time (Table 3) so that the mean LD50 for the second hour was about 15 per cent higher than for the first, and the slope increased significantly. Maximum inhibition of respiration for mycelium and spores were 89 and 94 per cent, respectively, at 36-50 ppm. At levels of PCP causing 99 per cent inhibition of germination, spore respiration was inhibited 50-65 per cent. Again no significant difference was found in sensitivity of CO_2 evolution and O_2 consumption mechanisms of spores (Table 4).

Tetramethylthiuram disulfide. This toxicant showed a wider range of LD50 values for the three tests than any other except the related dithiocarbamate derivative, DSE (Table 1). The values for inhibition of spore respiration and mycelial respiration were 2.7 and 6 times that for germination. The former decreased rapidly with time while the latter did not change. As a result, the sensitivity of spore respiration during the third hour was about the same as that of mycelium. Because of limited solubility, maximum inhibition of respiration could not be determined. At levels of TMTD causing 99 per cent inhibition of germination, spore respiration was reduced only 20-55 per cent. The sensitivity of spore respiration as measured by CO_2 evolution and O_2 consumption was the same (Table 4).

Disodium ethylenebisdithiocarbamate. This dithiocarbamate derivative was less toxic in all three tests than TMTD and, in fact, caused no inhibition of mycelial respiration up to 500 ppm (Table 1). In contrast to TMTD, DSE caused increasing inhibition of spore respiration with time

Table 3. Change in percentage inhibition of O_2 consumption by spores with time.

Toxicant		Dosage (p.p.m.) and Per Cent Inhibition						LD50	Slope
EMC	(3-7)	p.p.m.	1.8	3.6	5.4	7.1			
		1st hr.	43	58	74	89		2.5	0.28
		2nd hr.	54	73	82	90		1.6	0.27
Actidione	(2-2B)	p.p.m.	0.17	0.34	0.51				
		1st hr.	33	46	52			0.45	0.10
		2nd hr.	13	28	46			0.57	0.34
		3rd hr.	-3	-1	12			----	----
		4th hr.	-5	-5	-1			----	----
PCP	(3-6)	p.p.m.	7.1	10.7	14.3	17.7			
		1st hr.	36	63	71	81		9.2	0.46
		2nd hr.	9	57	78	83		10.2	0.75
TMTD	(3-10)	p.p.m.	20	30	40	50			
		1st hr.	35	53	62	80		27.6	0.41
		2nd hr.	25	33	46	69		38.5	0.42
		3rd hr.	23	7	16	36		58.0	0.66
DSE	(2-23)	p.p.m.	20	40	60	80	100		
		1st hr.	21	30	40	46	50	100	0.12
		2nd hr.	15	30	51	65	76	59	0.45
DNP	(2-7)	p.p.m.	107	128	150	172	385		
		1st hr.	-12	37	70	81	94	136	0.78
		2nd hr.	-10	42	67	85	93	134	0.77
		3rd hr.	-10	46	62	89	94	132	0.80

except at the lowest concentrations, and the LD50 for the second hour averaged about 40 per cent less than for the first hour in 8 trials. The typical example in Table 3 shows that in addition to the increasing inhibition at higher concentrations there was decreased inhibition below 40 ppm, which resulted in a large increase in slope of the dosage-response curve in the second hour. A maximum inhibition of spore respiration of 83 per cent was reached between 80 and 190 ppm. Although the LD50 values for CO_2 evolution and O_2 consumption of spores were the same, there was evidence of somewhat higher slope value for the former. Finally, toxicant levels causing 99 per cent inhibition of germination inhibited spore respiration only 30-55 per cent.

2,4-Dinitrophenol. This was the least toxic of all the compounds tested on germination and spore respiration (Table 1). Like PCP it was slightly more toxic to mycelial respiration than to spore respiration. Unlike PCP, however, inhibition of spore respiration did not change significantly with time (Table 3). Respiration of both spores and mycelium was stimulated at low concentrations of DNP. A maximum inhibition of spore respiration of 94 per cent was reached at about 385 ppm. Toxicant levels causing 99 per cent inhibition of germination inhibited spore respiration 30-65 per cent. Finally, as with the other toxicants, no significant differences were observed in the sensitivity of CO_2 evolution and O_2 consumption of spores (Table 4).

Table 4. Comparison of O_2 and CO_2 inhibition of spore respiration with time.

Toxicant		Dosage (p.p.m.) and Per Cent Inhibition				LD50	Slope
EMC	(3-30)	p.p.m.		2.0	4.0	6.0		
		1st hr.	O_2	39	64	73	2.79	0.30
		2nd hr.		49	80	85	2.04	0.39
		1st hr.	CO_2	41	66	75	2.63	0.30
		2nd hr.		53	82	86	1.89	0.37
Actidione	(1-26)	p.p.m.		0.7	1.4			
		1st hr.	O_2	67	73		0.13	0.02
		2nd hr.		61	80		0.52	0.29
		3rd hr.		33	73		0.94	0.51
		1st hr.	CO_2	53	69		0.60	0.17
		2nd hr.		63	80		0.44	0.24
		3rd hr.		37	77		0.87	0.51
PCP	(3-29B)	p.p.m.		7.1	10.7	14.3		
		1st hr.	O_2	26	63	67	9.2	0.65
		2nd hr.		12	47	71	11.1	0.66
		1st hr.	CO_2	22	63	63	9.5	0.67
		2nd hr.		12	45	68	11.5	0.65
TMTD	(3-27)	p.p.m.		20	30	50		
		1st hr.	O_2	50	67	81	22.0	0.38
		2nd hr.		27	50	81	30.0	0.50
		1st hr.	CO_2	46	69	85	21.2	0.42
		2nd hr.		25	49	84	29.5	0.57
DSE	(2-25)	p.p.m.		40	80	120		
		1st hr.	O_2	35	58	68	64	0.25
		2nd hr.		27	70	79	58	0.51
		1st hr.	CO_2	33	59	74	63	0.33
		2nd hr.		24	79	86	56	0.62
DNP	(2-16)	p.p.m.		100	125			
		1st hr.	O_2	22	70		115	0.85
		2nd hr.	CO_2	7	64		120	0.89

DISCUSSION

The QM460 M. verrucaria strain proved to be well suited for this study. Spore production on the Sinden, Mix, and Siu (17) medium was abundant, and the cultures only rarely showed nonsporulating variants. Spore yields were excellent and untreated spores almost always germinated 99 to 100 per cent in drops of Mandels and Norton's medium (10) on glass slides. Mycelium production in the shake cultures, likewise, was quite reproducible and very similar in character to that reported by Darby and Goddard (4, 5).

The respiratory properties of both spores and mycelial pellets also were generally in good agreement with those of previous reports. The

Q_{O_2} for spore respiration, 80, was higher than that, 63, found by Mandels and Norton (10), but this difference may have been due to the fact that the former value was based on initial dry weight while the latter was on dry weight at the end of the first hour after some growth had occurred. The only significant difference in mycelial respiration from the report of Darby and Goddard (4) was the higher RQ, for which there is no present explanation.

Germination LD50 values for the toxicants studied with M. verrucaria ranged from about 2 to 90 ppm in the following order: EMC, actidione, PCP, TMTD, BQ, DSE, and DNP. It is difficult to compare the sensitivity of M. verrucaria to those compounds with reports on other fungi because of differences in germination tests used. In the case of TMTD, however, M. verrucaria appears to be less sensitive than the fungi studied by Manten et al. (11), and with actidione it is of intermediate sensitivity compared with the species tested by Whiffen (24) and Wallen et al. (23). All the toxicants tested in the present work gave linear dosage-response curves for germination, whose slopes were steep and of similar values (0.74-0.88), in agreement with the report of McCallan et al. (12) that organic fungicides generally give steep slopes.

With the exception of actidione, the LD50 values of the toxicants for spore respiration were all higher than for germination but ranked in the same order. The ratios (respiration/germination) ranged from 0.4 to 2.6 for the periods of maximum sensitivity. It must be recognized that this difference may have been affected by the higher spore density (20-30x) used in the respiration tests. If M. verrucaria spores accumulated toxicants to the extent observed in the recent work of Miller et al. (14), the higher spore density in the respiration tests might be expected to have required even higher toxicant concentrations than those used to give the same dosage on a spore weight basis. However, the sensitivity of respiration at the LD50 level is apparently greater in comparison with germination than is indicated above on the basis only of toxicant concentration in the medium. The fact that the relative order of LD50 values for respiration and germination was the same would indicate that the extent of accumulation, if it occurred, may have been similar for the various compounds. Until studies of accumulation such as those of the Boyce Thompson group are made with the toxicants used in the present work, it will be impossible to determine what effect this phenomenon would have on the interpretation of the relative dosage response of respiration and germination.

The slopes of dosage-response curves for spore respiration varied more among the toxicants and, with exception of DNP, were much lower than for germination. In most cases (especially DSE, PCP, DNP, and actidione) the curves showed breaks above LD50 which seemed to be due to the fact that respiratory inhibition reached maximum levels less than 100 per cent. Only with EMC, and possibly DNP, was inhibition of spore respiration essentially complete. This may indicate that there are respiratory pathways in M. verrucaria which are insensitive to the other toxicants. Not only did most of the toxicants not completely inhibit spore respiration even at relatively high concentrations but the levels which were just sufficient to stop germination (LD99) caused only partial inhibition of respiration. Variation among the toxicants both in the maximum

percentage inhibition and in that at 99 per cent inhibition of germination constitutes one type of evidence of differences in their action on respiration.

The toxicants also varied in the effect of time of treatment on inhibition of spore respiration. Inhibition by EMC and DSE increased with time, particularly at the higher concentrations of the latter. This increase was due more likely to slow penetration than to decreasing sensitivity during spore germination since mycelial respiration was much less sensitive, especially in the case of DSE. Another possible cause of increasing inhibition with time would be chemical change in the toxicants to more active compounds. Conversely, inhibition of spore respiration decreased with time at all concentrations of TMTD, at levels of actidione initially inhibiting up to 60 per cent, and at low levels of PCP and possibly DSE. Only DNP showed little or no change in inhibition with time. Possible reasons for the rapid recovery of spore respiration were investigated in the case of actidione (22). The results showed that there was no significant decomposition of actidione during the incubation period and that spores removed the toxicant from the medium. Whether the recovery was due simply to decreasing spore sensitivity or whether actual detoxication was involved has not yet been determined.

Comparison of sensitivity of CO_2 evolution and O_2 consumption of spores gave no evidence of difference in mechanism of respiratory inhibition among the toxicants. The only differences observed were in the somewhat higher slopes of the CO_2 dosage-response curves of the dithiocarbamate derivatives.

With the possible exception of PCP and DNP, the LD50 values for mycelial respiration were all higher than for spore respiration. The difference was most striking with DSE, to which the mycelium was only about one-tenth or even less sensitive than the spores. In all cases the differences in LD50 values would be somewhat higher, since an average of 4.14 mg. of mycelium was used per flask as compared with 3.25 mg. of spores. On the basis of equal dry weights of tissue, mycelium was about a third more sensitive to the phenols and two to eight or more times more resistant to EMC, actidione, and DSE than were spores. Clear-cut changes in inhibition of mycelial respiration with time were observed only with actidione. Maximum inhibition values for mycelial respiration, where they were determined, were roughly the same as for spore respiration. Finally, comparison of slopes of dosage-response curves for respiration of mycelium and spores showed no apparent correlation. It is evident that this group of toxicants varied considerably in their relative effects on spore and mycelial respiration, but the extent to which this was due to changes in permeability rather than to changes in metabolic properties of the organism during growth can not yet be decided.

The present work indicates that in comparing the action of fungicides on germination and respiration it is important to consider not only LD values but also the nature of the dosage-response curves and the changes in inhibition with time as well. On this basis the group of compounds studied has shown a sufficiently close correlation of toxicity to germination and respiration to warrant further investigation of the mechanism of respiratory inhibition. The pattern of respiratory inhibition has also indicated possible differences among the toxicants in mechanism of action.

To determine with more certainty the extent to which fungicidal action is based on respiratory inhibition and to locate the site of action, it will be necessary to investigate the effect of the toxicants on specific metabolic pathways and individual enzyme systems. Finally, although the data presented indicate a general relation between germination and respiration inhibition, the toxicity indices are sufficiently different to question the use of either germination or respiratory data as the sole basis of fungicidal assay.

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SUMMARY

The effect of nine representative organic fungicides on Myrothecium verrucaria was measured by comparison of LD50 values, slopes of dosage-response curves, and time of treatment for germination and spore and mycelial respiration. Although the LD50 values in germination tests were lower than those for respiration, the greater spore density in the latter indicated that respiration may have been more sensitive than germination. With the exception of actidione, the toxicants ranked in the same order of activity. Mycelial respiration was generally less sensitive than spore respiration. Changes in inhibition of spore respiration with time among the toxicants and variation in maximum inhibition indicated possible differences in mechanism of action. No difference in sensitivity of CO_2 evolution and O_2 consumption of spores was observed.

REFERENCES

1. Barratt, R.W. and J.G. Horsfall. Fungicidal action of metallic alkyl bisdithiocarbamates. Connecticut Agr. Exp. Sta. (New Haven) Bull. 508. 1947.
2. Clowes, G.H.A., A.K. Keltch, C.F. Strittmatter, and C.P. Walters. Action of nitro- and halophenols upon oxygen consumption and phosphorylation by a cell-free particulate system from Arbacia eggs. Jour. Gen. Physiol. 33:555-561. 1950.
3. Cox, C.E., H.D. Sisler, and R.A. Spurr. Identity of gaseous toxicants from organic sulfur fungicides. Science 114:643-645. 1951.
4. Darby, R.T. and D.R. Goddard. Studies of the respiration of the mycelium of the fungus Myrothecium verrucaria. Amer. Jour. Botany 37:379-387. 1950.
5. _____, _____. The effects of cytochrome oxidase inhibitors on the cytochrome oxidase and respiration of the fungus Myrothecium verrucaria. Physiologia Plantarum 3:435-446. 1950.

6. Dimond, A.E., J.G. Horsfall, J.N. Neuberger, and E.M. Stoddard. Role of the dosage-response curve in the evaluation of fungicides. Connecticut Agr. Exp. Sta. (New Haven) Bull. 451:635-667. 1941.
7. Foote, M.W., J.E. Little, and T.J. Sproston. On naphthoquinones as inhibitors of spore germination. Jour. Biol. Chem. 181:481-487. 1949.
8. Hochstein, P.E., and C.E. Cox. Effect of tetrachloro-p-benzoquinone on certain fermentative enzyme systems in fungi. (Abstract) Phytopath. 42:13. 1952.
9. Hoffman-Ostenhof, Otto. Mechanism of the antibiotic action of certain quinones. Science 105:549. 1947.
10. Mandels, G.R. and A.B. Norton. Studies on the physiology of spores of the cellulolytic fungus Myrothecium verrucaria. Research rept. from the Quartermaster General Laboratories. Microbiology series no. 11. 1948.
11. Manten, A., H.L. Klöpping, and G.J.M. Van der Kerk. Investigations on organic fungicides. I. The antimicrobial spectrum of the antifungal substance tetramethylthiuram disulphide. Ant. v. Leeuw. Jour. Microbiol. and Serol. 16:45-55. 1950.
12. McCallan, S.E.A., R.H. Wellman, and F. Wilcoxon. An analysis of factors causing variation in spore germination tests of fungicides. III. Slope of toxicity curves, replicate tests, and fungi. Contr. Boyce Thompson Inst. 12:49-77. 1941.
13. McElroy, W.D. and B. Glass, editors. Phosphorus Metabolism. Contr. 23. McCollum-Pratt Inst. The Johns Hopkins Press, Baltimore, Md. 1951.
14. Miller, L.P., S.E.A. McCallan, and R.M. Weed. Rate of uptake and toxic dose on a spore weight basis of various fungicides. Contr. Boyce Thompson Inst. 17:173-195. 1953.
15. Richert, D.A., R. Vanderlinde, and W.W. Westerfeld. The composition of rat liver xanthine oxidase and its inhibition by antabuse. Jour. Biol. Chem. 186:261-274. 1950.
16. Shirk, H.G. and H.E. Byrne. Effect of some nitrophenols on respiration of Myrothecium verrucaria spores. Jour. Biol. Chem. 191-783-786. 1951.
17. Sinden, J.W., A.J. Mix, and R.G.H. Siu. Effect of environment and mineral nutrition of cellulolytic activity on fungi. Research report from the Quartermaster General Laboratories. Microbiology series No. 8. 1948.
18. Singer, T.P. Enzyme inhibitors and the active groups of proteins. The Brewers Digest 20, No. 8:85-88, 94. No. 9:104-106, 109. 1945.
19. Sisler, H.D. and C.E. Cox. Some effects of tetramethylthiuram disulfide on metabolism of conidia of Fusarium. (Abstr.) Phytopath. 41:32. 1951.
20. Siu, R.G.H. Microbial Decomposition of Cellulose. Reinhold Publishing Corp. New York. 1951.
21. Umbriet, W.W., R.H. Burris, and J.F. Stauffer. Manometric Techniques and Tissue Metabolism. Burgess Publ. Col., Minneapolis, Minnesota. 1949.

22. Walker, A.T. and F.G. Smith. Effect of actidione on growth and respiration of Myrothecium verrucaria. Proc. Soc. Exp. Biol. and Med. 81:556-559. 1952.
23. Wallen, V.R., M.D. Sutton, and A.J. Skolko. The effect of actidione on the growth of certain pathogenic fungi and on the germination of pea seed. Phytopath. 40:156-160. 1950.
24. Whiffen, A.J. The activity in vitro of cycloheximide (actidione) against fungi pathogenic to plants. Mycologia 42:253-258. 1950.
25. Wilcoxon, F. and S.E.A. McCallan. Theoretical principles underlying laboratory toxicity tests of fungicides. Contr. Boyce Thompson Inst. 10:329-338. 1939.

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MEASUREMENT OF SOIL TEMPERATURE WITH LABORATORY MERCURY-IN-GLASS THERMOMETERS[1]

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In the study of certain problems the evaluation of soil temperatures becomes important. The instruments used to measure soil temperature vary widely and many are quite expensive. Several types are available, the most common being the liquid-in-metal recording soil thermograph, thermocouples, and the mercury-in-glass soil thermometer.

Soil thermographs consist of a metal cylinder or sensitive element which can be buried in the soil for an indefinite time. The sensitive element, which is connected to the recording part of the instrument by a small tube, is filled with a liquid which expands or contracts as the soil temperature changes. This activates a bellows which controls the pen. The thermal sensitive element has a relatively large heat capacity and lags behind rapid temperature changes in the soil. These instruments are costly, but have the advantage of being self-recording. Mail (1937) found 2-3°F differences with thermocouples, if the thermograph was not installed with care. Turnage (1937) found a discrepancy of 1-3°F if the recording part of the instrument was at a widely different temperature than the sensitive element. This was partially counteracted by installing the recording part where a minimum of diurnal fluctuation would be encountered.

Thermocouples, formed by the junction of two dissimilar metals, have a small heat capacity because of the small size of the thermojunction and will indicate rapid changes in temperature. The disadvantage of thermocouples is that a reference junction must be maintained at a known temperature or a compensating type reference junction must be used. Automatic recorders are available but expensive.

Mercury-in-glass thermometers used for measuring soil temperatures are of several types. In one type the thermometer has an angle or bent tube. The bulb end is inserted into the soil to the desired depth while the bent section lies on or at an angle to the surface. This makes the thermometer somewhat easier to read. Straight tube thermometers may be of the type used by the U.S. Weather Bureau, where the thermometer is enclosed in a wooden case, open at the bulb end and above the ground where the scale is marked. The thermometer itself is in contact with the soil only at the bulb end. These thermometers are permanently installed and do not have to be moved to be read. In another straight type

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the thermometer is hung in a steel pipe, and the thermometer is pulled out to be read. Another type has a metal point in which the thermometer bulb is located. These thermometers are pushed into the soil to the depth desired, but can only be used to measure temperatures a few inches deep.

If none of the regular soil thermometers are available, the possibility of using laboratory, mercury-in-glass thermometers may arise. These are easily obtained, and because of the low cost can be used in numbers which may not be possible in the other types.

Certain errors are present in mercury-in-glass thermometers.

1. Elastic error. If a thermometer which has been at a high temperature suddenly changes to a low temperature it will be in error by a small amount. Because of relatively slow changes in soil temperature this error is negligible. The glass bulb may also contract over a period of time although this can be corrected for by recalibration if the accuracy of the experiment requires it.

2. Emergence of stem error. An error introduced if the entire thermometer is not in a medium of the same temperature. Although difficult to evaluate exactly, it is small for mercury-in-glass thermometers that would be used for soil temperature measurements. This error is discussed in Middleton (1942).

3. Parallax error. An error introduced due to the observer not reading the thermometer from the proper level. This can be eliminated by careful observation.

4. Radiation error. An error caused by radiation to or from the thermometer. In the bent type or laboratory thermometer no protection is present, and the radiation error might become appreciable. For thermometers enclosed in a wooden case, the case acts as a radiation shield.

5. Conduction error. An error due to heat being conducted along the stem as a result of temperature gradient in the surrounding medium from one end of the thermometer to the other. Conduction down the stem may allow the heat received by radiation on the stem of the thermometer to be conducted to the bulb in the ground. For the thermometer in the wooden case, this should be small. An examination of the coefficient of conductivity of glass and moist soils shows them to be in the same range. Where glass has a coefficient of 0.0015 cal/sec/cm^2/C$^\circ$/cm, fine sandy loam had a coefficient of 0.0026 and wet kaolin a coefficient of 0.0014. Conduction down the stem may not be a large error in wet soils.

The purpose of this study was to measure the effect of different methods of exposing laboratory mercury-in-glass thermometers in measuring soil temperatures. Only the average error was considered and no attempt was made to evaluate the errors for individual readings.

PROCEDURE

A bare ground plot 100 by 60 feet was subdivided into 8 replications for this study. Four methods of exposure were used:

1. Thermometer perpendicular to ground surface with no shielding.
2. Thermometer at an angle of 45° to the ground surface with no shielding.

3. Thermometer perpendicular to the ground surface with an aluminum foil shield.
4. Thermometer at an angle of 45° to the ground surface with an aluminum foil shield.

The shield consisted of a cylinder of aluminum foil approximately 3/4 inch in diameter which was placed over the part of the thermometer above the ground. Other more efficient shields could be designed but it was not believed the time spent would be worth the accuracy gained. The thermometers were graduated in half degree Fahrenheit units and read to the nearest tenth of a degree.

Observations were taken on both clear and cloudy days at approximately 2:30 P.M. in early summer at depths of 1, 3, and 6 inches. Temperatures at this time of day are near the maximum at shallow depths. Radiation errors would be expected to be larger during this time of day than at night.

RESULTS AND DISCUSSION

Since radiation is a dominant factor in soil temperatures, differences might be expected due to it. To investigate this, the data were divided into two groups, days clear and days cloudy at the time of observation. The cloud cover experienced during the investigation was largely of the cumulus type.

The average soil temperatures measured at the various depths by the different methods of exposure are given in Table 1. Temperatures for different depths were not taken on the same day.

Table 1. Average soil temperatures measured by four methods of exposing thermometers and by thermocouples, with differences from thermocouples in parenthesis. Average of 8 days for each cloud cover.

Depth	Cloud cover	Perpendicular unshielded	Slanting unshielded	Perpendicular shielded	Slanting shielded	Thermocouple
1"	Cloudy	88.7 (+1.0)	89.3 (+1.6)	87.3 (-0.4)	87.7 (0)	87.7
1"	Clear	102.9 (+1.0)	103.3 (+1.4)	99.7 (-2.2)	100.4 (-1.5)	101.9
3"	Cloudy	81.0 (0)	80.6 (-0.4)	80.9 (-0.1)	80.0 (-1.0)	81.0
3"	Clear	89.0 (+1.0)	88.5 (+0.5)	88.8 (+0.8)	88.4 (+0.4)	88.0
6"	Cloudy	80.1 (0)	79.3 (-0.8)	80.0 (-0.1)	79.1 (-1.0)	80.1
6"	Clear	84.4 (+0.8)	83.2 (-0.4)	84.2 (+0.6)	82.6 (-1.0)	83.6

A statistical analysis of the data show a statistically significant difference, at the 1 per cent level, for methods of exposure at the 1" depth, on both clear and cloudy days. Although the differences were smaller for cloudy days, the error was also smaller. A comparison of the perpendicular and slanting exposures showed a significant difference at the

5 per cent level, while shielded and unshielded differed significantly at the 1 per cent level. Shielding resulted in the ground being shaded around the thermometer with generally cooler temperatures. Unshielded readings were higher than the thermocouple readings. On cloudy days the shielded thermometers were more accurate. The slanting unshielded thermometer, being at a more direct angle to the radiation, and because more of the thermometer was in contact with the hot surface soil, was heated the most.

The differences were also about the same for the 3 and 6 inch depths. Differences between methods of exposure were significant for all except clear days at the 3" depth, where the error term was quite large. In all other cases the error term was very small. The differences between thermometer and thermocouple for both depths were 1°F or less. At the 3" and 6" depths there was little advantage in any method of exposure. The slanting shielded thermometer gave the largest differences from the thermocouples. At the 6" depth the difference between perpendicular and slanting exposures was highly significant on both clear and cloudy days. The difference was not significant for shielded and unshielded thermometers. Differences between replications were quite small and were not significant in any case.

In most problems of agricultural interest, soil temperatures measured within 1°F of the true value are of sufficient accuracy. Except for the 1" depth, all four methods of exposure gave an accuracy within this limit. No method of exposure was decidedly better than the others.

The cloudy days in this experiment do not represent days overcast for the entire day since no weather of this type occurred during the period of observation. The partly cloudy days, with the sun obscured by clouds at the time of observation, at least partially reduced any error due to radiation falling on the thermometers.

On overcast days with a heavy cloud cover, or at night, one would expect the error to be small. Data for individual days with heavy overcast, or clear or cloudy nights, taken with the thermometers exposed perpendicular to the ground surface, show the error to be within $\frac{1}{2}$°F at 1 inch, with practically no error at 6 inches.

On the basis of these observations, laboratory thermometers exposed perpendicularly to the ground surface measure soil temperature with an error of about 1°F for depths of 1". For greater depths the error is 1°F or less on clear days and for cloudy days almost zero. Unless great accuracy is desired, these thermometers give a satisfactory estimate of soil temperature at these depths. At shallow depths the error could be considerably greater if the thermometer was exposed at an angle of 45°. Shielding of the type used did not increase greatly the accuracy. It appears that an unshielded thermometer will give an estimate of soil temperatures below 1" of sufficient accuracy for most agricultural problems.

SUMMARY

Laboratory mercury-in-glass thermometers were used to measure soil temperature at 1", 3", and 6" depths by means of four methods of exposure.

1. Thermometer perpendicular to ground surface with no shielding.
2. Thermometer at an angle of 45° to the ground surface with no shielding.
3. Thermometer perpendicular to the ground surface with an aluminum foil shield.
4. Thermometer at an angle of 45° to the ground surface with an aluminum foil shield.

Under clear skies unshielded thermometers exposed perpendicular to the surface had an error of 1°F or less. Under cloudy skies, except for the 1" depth the error was negligible. The error was always positive.

An aluminum shield increased the accuracy very little. Exposing the thermometer at a 45° angle resulted in slightly lower average errors at 3" and 6" but a slightly larger error at the 1" depth. Shielding this thermometer at 1" increased the accuracy for cloudy days, but decreased the accuracy on clear days.

It appears that the laboratory mercury-in-glass thermometer can be used to measure soil temperatures below 1" with an average error of 1°F or less. The advantage of these thermometers is their low cost, thus allowing them to be used in much larger numbers.

REFERENCES

Mail, G.A. Accuracy of soil thermograph. Soil Sci. 43:27-30. 1937.

Middleton, W. E. Meteorological instruments. University of Toronto Press, Toronto, Canada. 1942.

Turnage, W.V. Note on the accuracy of soil thermographs. Soil Sci. 43:465-476. 1937.

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VIRUS SPREAD IN NURSERY BLOCKS OF SOUR CHERRIES IN SOUTHWEST IOWA[1]

O.F. Hobart, Jr., H.C. Fink, and W.F. Buchholtz[2]

Spread of virus into and within nursery blocks of young cherry trees could be a major factor in virus contamination in such blocks. Conversely, evidence for lack of spread would assure the possibility of producing a virus-free crop from virus-free budwood and virus-free understock seedlings. The first approach to this problem was to determine whether there was or was not any virus spread in sour cherry blocks in southwest Iowa nurseries. Reported here is positive evidence of such spread during the growing seasons of 1949, 1951, and 1952.

Recorded Observations of Virus Spread in Sour Cherries

Spread of virus in sour cherry orchards has been observed by several workers. Keitt and Clayton (2) kept records of virus incidence in five orchards (2593 trees) for five years and reported an annual increase of approximately 3 per cent. Rasmussen (6) observed in one orchard a rate of spread of only 1 per cent per year, while in another the rate of spread was 21 per cent per year. Lewis (3) felt that some young trees were infected when set in the orchard and that virus was spread from one tree to another in the orchard. On the other hand, Mills (4), as late as 1936, stated:

> Since prevailing temperatures following the petal fall stage cause a great variation in the apparent amount of virus yellows present in an orchard from year to year, it appears that no data to date, based on the apparent incidence of yellows in two different years, prove or disprove spread of the cherry yellows virus after the trees are set in the orchard.

In 1947, Mills reiterated that there was no definite evidence that the yellows virus was spreading in the orchard (5).

Observations by Willison, Berkeley, and Chamberlain (8) in Canada during a period of years prior to 1948 revealed that a greater percentage of trees are likely to be infected with necrotic ring spot than with yellows when the orchard is set out and that rates of spread are largely determined by initial incidence and by the relative position of affected and "healthy" trees at planting. Their observations furthermore revealed

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[1]Journal paper No. J-2636 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 1060. Taken from theses submitted by the first two authors for the degree, Doctor of Philosophy.

[2]Plant Pathologist, United Fruit Company, Guaro, Cuba; Associate Professor of Plant Pathology, Pennsylvania State College; and Associate Professor, Iowa State College, respectively.

that cherry yellows tends to spread more frequently to adjacent than to more remote healthy trees and its dissemination appears to be influenced to some extent by prevailing winds. In 1949, Willison (7) reported a range of incidence of cherry yellows of from 5.1 to 90.0 per cent and annual incidence of new cases in the range of 0.0 to 39.6 per cent in the orchards surveyed.

The observations to be reported in this paper are based on periodic indexings of sour cherry trees in nursery blocks. No other such recorded observations have come to the authors' attention.

PROCEDURE

In each case a sample of 100 trees in a particular cherry nursery block was indexed during early or midseason and the same or a comparable sample indexed again late in or at the end of the season, in one case after the next season. During the 1952 season, the 100 tree samples in three blocks consisted of ten lots of ten consecutive trees in the row, with an eleventh inoculated tree in the center, so as to yield an indication of pattern as well as amount of spread.

Unless otherwise stated, all indexing was on Prunus tomentosa, which has been found to be a reliable indicator plant for virus which induces necrotic ring spot on sour cherry (1).

Amount of Spread in 1949 and 1951

In 1949, samples of trees from each of two Montmorency sour cherry blocks were indexed on July 16 and similar samples were indexed on September 1. Both blocks had been propagated from indexed virus-free Montmorency buds so that presumably the only virus in them was that introduced through the rootstock. One was isolated one-fourth mile from other Prunus; the other actually was part of a commercial block of cherries, a sample of the remainder of which had been indexed and 32 per cent of the trees found to contain virus.

Samples from the unisolated block were found to contain 9 and 37 per cent of infected trees on July 16 and September 1, respectively, a highly significant difference according to the chi-square test. Similarly, samples from the isolated block were found to contain 2 and 8 per cent of infected trees on the respective dates, a nonsignificant difference.

A sample of trees from a second isolated block, likewise propagated from indexed virus-free budwood, was also indexed on September 1, 1949, and found at that time to contain 20 per cent of infected trees. A sample of already budded P. mahaleb understock seedlings in this block had been indexed on September 14, 1948, and found to contain 18 per cent of infected trees.

It is evident that in all three of these blocks there was a higher percentage of infected trees at the second than at the first indexing. The increase was appreciable and numerically significant only in the unisolated block.

In 1951, a sample of 100 trees was marked in each of three blocks of Montmorency cherries. Two blocks had been propagated from scionwood and root stocks of undetermined virus content and were not isolated from

other Prunus in the nursery. The third block had been propagated from indexed virus-free scionwood but on rootstocks of undetermined virus content, and was isolated by at least one-fourth mile from other Prunus.

Samples in all three blocks were indexed on July 4 and again on August 4. Initial percentages of infected trees in the samples in the unisolated blocks propagated from commercial scionwood were 47 and 68; final percentages were 58 and 77, increases of 11 and 9, respectively. Initial and final percentages for the sample in the isolated block propagated from indexed virus-free budwood were 9 and 13, respectively, an increase of 4. In all cases, trees found to contain virus by the first indexing also were found to contain virus by the second indexing.

Amount and Pattern of Spread in 1952

The experiments in 1949 involved indexing two different random samples of single trees in a given block early and late in the growing season. In 1951, the same sample of single trees in a given block was indexed twice during the growing season. A similar procedure was undertaken in 1952, except that the 100 tree sample in a given block consisted of ten groups of ten consecutive trees in the row. An eleventh tree, the middle one, in each group of ten – really eleven – was inoculated on June 25 with a known source of necrotic ring spot and yellows. Each tree was then indexed three times, on June 25, again on August 1, and finally on September 17.

This procedure was followed in three commercial blocks of cherries, none of which was isolated and all of which had been propagated from indexed virus-free budwood on commercial understocks of undetermined virus content. Twenty of the 30 inoculations with known virus were successful. There was failure of bud union in each case of unsuccessful transmission. Results of indexing on August 1 and September 17 are presented in Diagram 1. Indexing on June 25 was a failure, apparently because of extreme immaturity of cherry buds inserted on P. tomentosa.

Percentages of infected trees in the three blocks on August 1, excluding inoculated trees, were 17, 10, and 12. The precentages in these three blocks on September 17 were 22, 16, and 18, increases of 5, 6, and 6, respectively. Examination of Diagram 1 reveals that of the 17 new cases according to the September 17 indexing, eight appeared in groups not adjacent to previously infected trees and three were single trees isolated from other infected trees by one or more intervening healthy trees in the row.

SUMMARY AND CONCLUSIONS

In three nursery blocks of sour cherry, in each of three years, 1949, 1951, and 1952, samples of trees were indexed at intervals of 30 days (1951) and about 45 days (1949, 1952) during the growing season and, in one case, one year (1948-1949). In all instances there were more virus-infected trees at the time of the second indexing than at the first.

In three instances, two in 1949 and one in 1951, the increases in percentage of infected trees in isolated blocks seemed to be relatively small (2, 6, 4) as compared to increases in unisolated blocks during the same season (28, 9, 11). The data are too limited to be conclusive, but are probably in accord with what might be expected.

Diagram 1. Relative positions of virus-infected Montmorency cherry trees in 30 11-tree groups in three nursery blocks in southwest Iowa according to indexings on August 1 and September 17, 1952.

Group[1]	Block I tree numbers											Block II tree numbers											Block III tree numbers										
	1	2	3	4	5	6[2]	7	8	9	10	11	1	2	3	4	5	6[2]	7	8	9	10	11	1	2	3	4	5	6[2]	7	8	9	10	11
1					A S	A S				A S				A S					S	S		A S								A S			
2						A S					A S						A S		A S										A S				
3	A S	S				A S	A S	A S									A S	A S				A S						A S		S			
4						A S	A S	A S						A S						A S									A S				A S
5																	A S												A S			S	S	
6						A S				A S		A S			A S		A S																	
7		A S	A S			A S					A S						A S														S	A S		
8	S	A S						A S					S	S	S		S						S	S	A S	A S	A S		A S	A S	A S	A S	A S	A S
9	S	A S	S	A S		A S					A S			A S																				
10						A S					S						A S									A S	A S	A S						

1 ten groups, 11 consecutive trees per group, in each block
2 central, inoculated tree of each group
A infected according to August 1 indexing
S infected according to September 17 indexing

The conclusion that there has been spread of virus in nursery blocks of sour cherries in southwest Iowa seems inescapable. It should be pointed out that all blocks studied contained infected trees at the time of first indexing by virtue either of some infected understock seedlings or infected budwood, or both, or perhaps lack of isolation from other Prunus, some of which are known, by virtue of other experiments, to have contained virus. Unfortunately, an isolated block propagated from indexed virus-free budwood on assuredly virus-free seedling understocks has not been available for study in southwest Iowa nurseries.

Occurrence of a few apparently newly infected trees not adjacent to previously infected trees in the same row suggests dissemination by an above ground vector.

The general nature of these results indicates that in southwest Iowa, isolation and virtual absence of virus in cherry blocks at the beginning of the growing season are necessary for reasonable assurance of a low percentage of infected trees at the end of the season.

REFERENCES

1. Fink, H.C. Prunus tomentosa as an index plant for necrotic ring spot of sour cherry. Phytopath. 40:9. (Abstr.) 1950.
2. Keitt, G.W. and C.N. Clayton. Further experiments on a virus disease of Prunus cerasus. Phytopath. 31:14. (Abst.) 1941.
3. Lewis, F.H. Ringspot and yellows of sour cherry in Pennsylvania. New York State Hort. Soc. Proc. 91:17-20. 1946.
4. Mills, W.D. Temperature effects on the expression of yellows virus in sour cherries. Phytopath. 36:353-358. 1946.
5. _____. Cherry yellows and cherry leaf spot (Coccomyces hiemalis). New York State Hort. Soc. Proc. 91:272-274. 1947.
6. Rasmussen, E.J. Cherry yellows in Michigan. Michigan State Hort. Soc. Ann. Rept. (1941) 72:116-118. 1942.
7. Willison, R.S. Necrotic ring spot. Twenty-eighth Ann. Rept. Can. Dis. Survey 1948:79. 1949.
8. _____, G.H. Berkeley, and G.C. Chamberlin. Yellows and necrotic ring spot of sour cherries in Ontario: distribution and spread. Phytopath. 38:776-792. 1948.

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THE MEASUREMENT OF SOIL TEMPERATURE[1]

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Records of soil temperatures are important in the solution of many agricultural problems – emergence of crops, soil borne diseases, bacterial activity and nutrient availability. At times, in order to get a better understanding of these problems, records of air temperatures are found inadequate. The soil temperatures must be measured. However, because of lack of instruments, the measurement of soil temperature may not always be a simple matter.

The question often arises: when and where should measurements be taken? To answer, the use of the measurements must be known. The ideal situation would be to have a sufficient supply of recording instruments available to measure all the desired locations. This is usually not feasible because of the expense involved. Many times a maximum, a minimum, or average temperature may suffice. Maximum and minimum thermometers will give this information, if available, but again may not be available because of the expense involved. To get the desired number of measurements it is often necessary to use mercurial thermometers. Since thermometers are not automatic recording devices, an observer must be present to record readings whenever they are wanted. In many cases, only maximum and minimum values are needed. When should these be taken? To answer this, one needs to know something about the time lag of heat movements in soils and the diurnal fluctuation.

The present set of observations was designed to give samples of the diurnal pattern at several depths and the time lag of maximum and minimum temperature occurrence at different depths.

METHODS AND RESULTS

Observations were taken using copper constantan thermocouples and a Brown recording potentiometer. Thermocouples were buried in Webster-Clarion mineral soil at depths of 0, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, and 12 inches, and in river sand and muck at depths of 0, 1, 2, and 4 inches. The sand and muck areas were established by digging wide holes in the mineral soil and filling these with muck and sand, so that all three soils were side by side. Data presented in Figs. 1, 2, and 3 were taken July 11-12 during a period of relatively clear skies. The soil was very dry during this period. Data taken July 14-15 during a period of general cloudiness with light rain on the 14th are presented in Fig. 4.

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[1]Journal paper No. J-2666 of the Iowa Agricultural Experiment Station, Projects 797 and 996.

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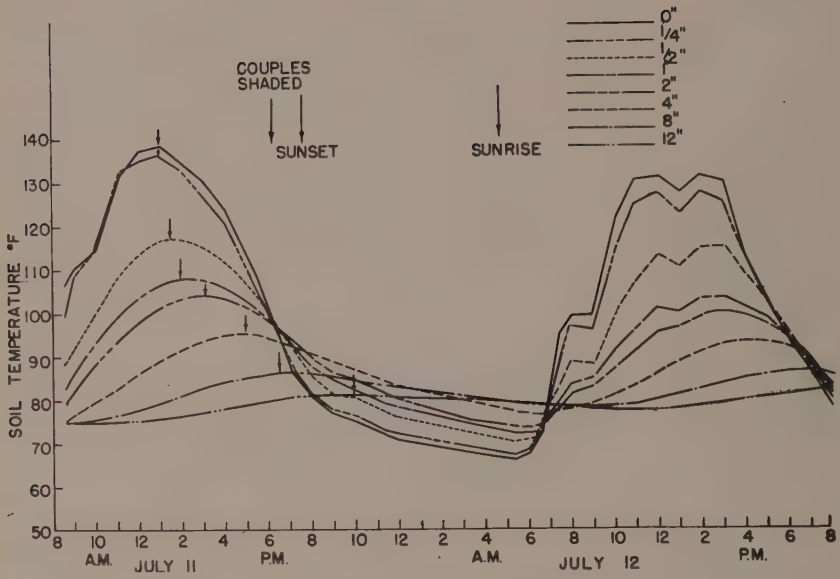

Fig. 1. Temperatures measured in garden soil, July 11-12.

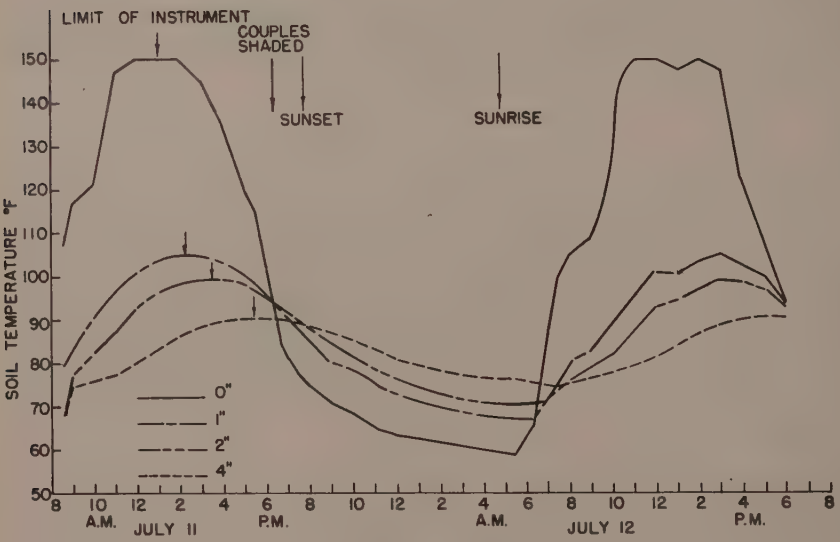

Fig. 2. Temperatures measured in muck, July 11-12.

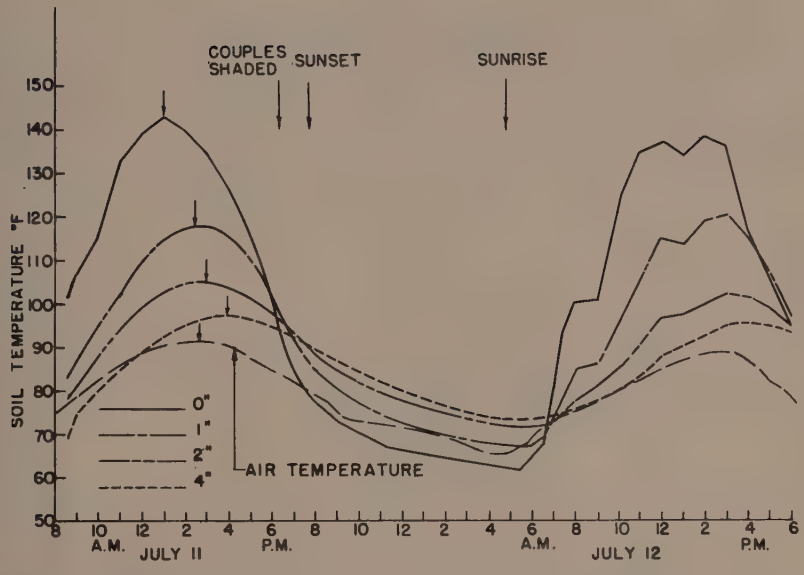

Fig. 3. Temperatures measured in sand and air temperatures at 5 feet, July 11-12.

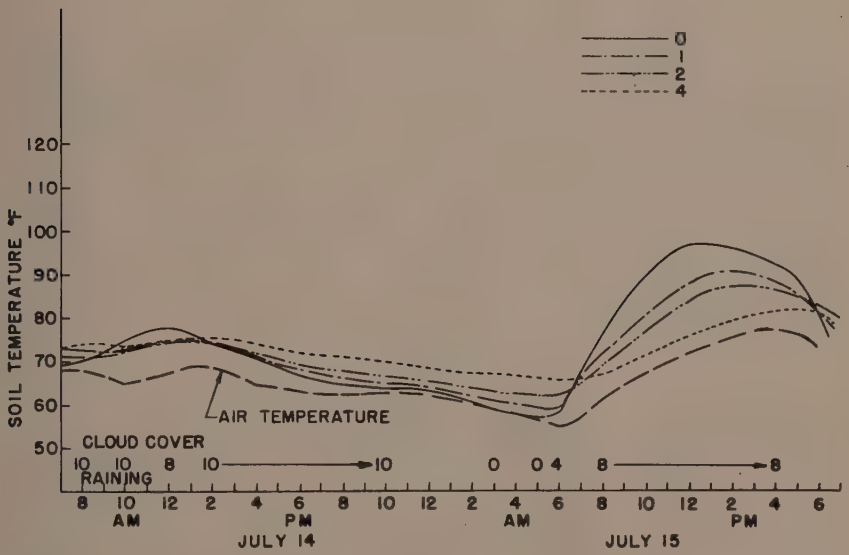

Fig. 4. Temperatures measured in garden soil and air temperatures at 5 feet, July 14-15.

DISCUSSION

The primary source of energy for heating the soil is radiant energy from the sun. Rainwater, because of its relatively large specific heat, exerts a powerful effect on soil temperatures during times of precipitation and cannot be neglected. During cold seasons the net heat transport may be from below. Other sources of heat energy are very small, and in most cases can be neglected.

If we assume only a vertical temperature gradient dt/dx exists, then the amount of heat W, which passes through a square centimeter area is given by

$$W = \lambda \, dt/dx$$

where λ is the heat conductivity of the soil in question. On the basis of this, one might expect higher soil temperatures at greater depths with increasing conductivity. The amount of temperature fluctuation found is not expressed this simply, however.

Geiger (1950) has presented the following equation to show the weakening of the temperature cycle with increasing depths:

$$\delta_2 = \delta_1 \exp (x_1 - x_2) (\pi \rho c / \lambda T)^{\frac{1}{2}}$$

$$\delta_2 = \delta_1 \exp (x_1 - x_2) (\pi / T a)^{\frac{1}{2}}$$

where a, called the thermal diffusivity, is defined by

$a = \lambda / \rho c$

δ_2 = range of temperature in degrees at depth x_2 in cm.

δ_1 = range of temperature in degrees at depth x_1 in cm.

ρ = density of soil

c = specific heat

λ = heat conductivity

T = 86,400 sec for diurnal heat wave.

The range δ_2 at a depth is a function of both δ_1, the range at a shallower depth and a, an expression including density, specific heat, and heat conductivity. This expression says that as the conductivity increases, the diurnal range increases, and as the density and specific heat increase the range decreases.

Geiger (1950) has also presented the equation for calculating the time lag of the movement of the maximum and minimum temperatures into the soil. Setting t_1 = time of reaching maximum or minimum temperature at depth x_1, t_2 = time of reaching maximum or minimum temperature at depth x_2, the result presented by Geiger is

$$t_2 - t_1 = (x_2 - x_1) (T/2\pi) (\pi \rho c / T \lambda)^{\frac{1}{2}}$$

$$t_2 - t_1 = (x_2 - x_1) (T/2\pi) (\pi / T a)^{\frac{1}{2}}$$

or

$$a = \frac{T}{2\pi} \quad \frac{(x_2 - x_1)^2}{(t_2 - t_1)^2}$$

This equation can be reduced to $a = 6870 (x_2 - x_1)^2 / (t_2 - t_1)^2$ for the diurnal change of soil temperature, which is the same as an equation given by Richards (1952). The last equation provides a method for calculating a by temperature measurements. The various soil constants can be evaluated by laboratory methods in order to compute a, but this is not a simple process.

The data presented in Figs. 1-4 can be used to get an estimate of when maximum and minimum temperatures might be reached at different depths

Table 1. Time of reaching maximum temperature and the diurnal range at different depths in sand, muck and mineral soil.

Depth in Inches	Time of reaching maximum temperature				Diurnal range		
	Sand	Muck	Mineral Soil	Air	Sand	Muck	Mineral Soil
July 11-12							
0	1:00	1:00*	1:00		81	91*	72
1	2:15	2:15	2:15		50	38	36
2	2:50	3:30	3:05		33	29	30
4	4:00	5:45	5:00		24	16	19
8			7:00				8
12			9:30				4
60				2:45			
July 15							
0			12:30				40
1			1:45				32
2			2:45				26
4			4:45				16
60				3:15			

*Temperature exceeded limit of instrument. Values estimated.

in the surface foot. Even at a depth of one foot the lag is considerable. In Table 1 the time of reaching maximum temperature and the range at each depth are given for the data taken July 11-12 and July 14-15. The time of reaching maximum temperature should be relatively uniform throughout the growing season. An examination was made of several years soil thermograph data recorded at depths of $2\frac{1}{4}$ inches and 6 inches at Ames. At the $2\frac{1}{4}$ inch depth, from April to August, there was little variation in the average time of occurrence of maximum and minimum temperature. The same was true for the 6 inch depth. Smith (1929) found that as a general rule maximum and minimum soil temperatures occur within certain times after maximum and minimum air temperatures. He found the lag time to be one hour at $\frac{1}{2}$ inch, 2 hours at 3 inches, 4 hours at 6 inches and 8 hours at 12 inches. Using a 5 foot air temperature as reference the data taken July 11-12 and July 14-15 show air temperature reaching a maximum after the 1 inch garden soil temperature and about the same time as the 2 inch soil temperature. Deeper depths lagged behind air temperature.

On the 15th because of cloudiness and moist surface soil the diurnal range was much smaller. Although the time of reaching maximum temperature was slightly earlier, the time lag between each depth was almost the same.

In Table 2 the values of $\underline{a}$ computed by means of $a = 6870 \frac{(x_2-x_1)^2}{(t_2-t_1)}$ are given and the diurnal range computed from the formula

$$\delta_2 = \delta_1 \exp (x_1-x_2)\left(\frac{\pi}{Ta}\right)^{\frac{1}{2}}$$ are also given.

Table 2. Values of "a" and estimated and measured diurnal ranges.

Substance	Depth (inches)	a[1]	Diurnal range formula	Estimated diurnal range at 2" or 4"	Measured diurnal range at 2" or 4"
Sand	1-2	.01005	$\delta_2 = .858\ \delta_1$	43	33
	1-4	.01005	$\delta_2 = .633\ \delta_1$	32	24
Mineral Soil	1-2	.00492	$\delta_2 = .808\ \delta_1$	29	30
	1-4	.00407	$\delta_2 = .486\ \delta_1$	17	19
Muck	1-2	.00219	$\delta_2 = .727\ \delta_1$	27	29
	1-4	.00251	$\delta_2 = .399\ \delta_1$	15	16
July 14-15					
Mineral Soil	1-2	.00342	$\delta_2 = .770\ \delta_1$	25	26
	1-4	.00342	$\delta_2 = .456\ \delta_1$	15	16

1 Computed by $a = 6870 \frac{(x_2-x_1)^2}{(t_2-t_1)^2}$

Except for sand, the computed and measured diurnal range was very close. The sand showed an extremely large diurnal variation at 1 inch which accounts for the difference between observed and computed. No values were computed for the 14th because the rain penetrating into the soil would cause a change in soil temperature not due to conduction.

If recording equipment is not available these equations may simplify taking certain measurements. For example, if either a set of maximum-minimum soil thermometers, or a recording soil thermograph are available, it can be used to measure the diurnal range at one depth. If the time of reaching maximum temperature at another depth can be determined by thermometers, then by use of the equations the diurnal range at the second depth may be computed. This may greatly simplify the time spent in the field taking observations.

Several general statements can be made about measuring soil temperature.

The data presented here for July 11-12 represent extreme diurnal ranges at the shallow depths for Iowa. On cloudy days, or days when the soil is wet, the diurnal range would be smaller.

To obtain maximum soil temperatures, measurements should be made from noon to 1:00 p.m. at the surface, 2:00 to 4:00 p.m. at 2 inches, 4:00 to 6:00 p.m. at 4 inches, 5:00 to 7:00 p.m. at 6 inches and 10.00 to 11:00 p.m. at 12 inches. Minimum temperatures should be recorded shortly after sunrise at shallow depths, about 2 hours after sunrise at 4 inches, 3 to 4 hours after sunrise at 6 inches, up to 7 to 8 hours after sunrise at 12 inches. Over a period of time observations at these times should give a good measure of the average maximum or minimum temperature. On individual days there may be errors because of changes in air mass, precipitation, and diurnal cloudiness. At depths of 6 inches or greater slight adjustments would need to be made on the times of taking observations on sand and muck; slightly earlier for sand and slightly later for muck.

REFERENCES

Geiger, R. The Climate Near the Ground. Harvard University Press, 1950.

Richards, S.J., R.M. Hagan, and T.M. McCalls. Soil temperature and plant growth. P. 328, Chapter 5 of: Soil Physical Conditions and Plant Growth. Edited by Byron T. Shaw. Academic Press, 1952.

Smith, A. Daily and seasonal air and soil temperatures at Davis, California. Hilgardia 4:77-112. 1929.

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THE HYDROGENATION OF VITAMIN B_{12}

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Although the hydrogenation of vitamin B_{12} was reported shortly after the isolation of the vitamin in crystalline form (3), little more has been done to establish the exact nature of the reaction other than to prove that cobalt is reduced to the bivalent state (2). In the present study we show that five hydrogen atoms are taken up, one molecule of base is liberated and that the base formed is methylamine as expected from the reduction of cyanide. That the oxidation of the reduced, bivalent form of the vitamin, known as B_{12r}, by oxygen is not simple has been pointed out (2); a quantitative study of the oxygen uptake has now been made.

EXPERIMENTAL WORK

A. Quantitative Hydrogenation of Vitamin B_{12}

Materials, apparatus, and procedure.

The vitamin B_{12} used was obtained from the Squibb Institute for Medical Research, New Brunswick, New Jersey. A solution of B_{12} in deaerated water was prepared and the concentration of the solution determined spectrophotometrically on a suitably diluted aliquot.

$$E^{1\%}_{1\ cm.} = 204 \text{ at } 361\ m\mu\ ;\ \text{mol. wt. taken as } 1350.$$

The hydrogenation apparatus used was the conventional, macro apparatus consisting of a conical hydrogenation flask in which an aqueous solution of the material was stirred magnetically, a manometer, and a 100-ml. buret. Mercury was used as the retaining liquid in the manometer and buret. The conical flask was provided with a short side arm covered by a rubber cap (Fig. I, J) which could be pierced by a hypodermic needle to permit injection of the sample following saturation of the solvent and platinum catalyst with hydrogen. For convenience in the subsequent oxygenation study, the flask was provided also with a second side arm (Fig. I, A) and was connected to the hydrogenation apparatus through two 90° elbows bearing ground glass joints. After catalyst and solvent had been placed in the flask, air in the apparatus was displaced by evacuating several times and admitting hydrogen after each evacuation. A measured volume of a solution of the vitamin was then introduced by means of a hypodermic syringe. Atmospheric pressure was maintained throughout the hydrogenation and the temperature of the solution was maintained within 1° by surrounding the hydrogenation flask with a water bath. The hydrogenation was continued until the volume remained constant for two hours.

Results.

The amount of hydrogen absorbed by vitamin B_{12} stopped somewhat short of five in the two experiments (Table 1). The rate of hydrogenation depended markedly on the amount of catalyst present.

Table 1. Hydrogenation of Vitamin B_{12}.

Experiment	Wt. B_{12}* (g.)	Wt. PtO (g.)	Final volume H_2 (ml. at S.T.P.)	Total time (hours)	Atoms of hydrogen absorbed
1.	0.576	0.100	22.2	21.5	4.64
2.	0.991	0.114	38.1	48.0	4.65

*Dry basis as determined spectrophotometrically.

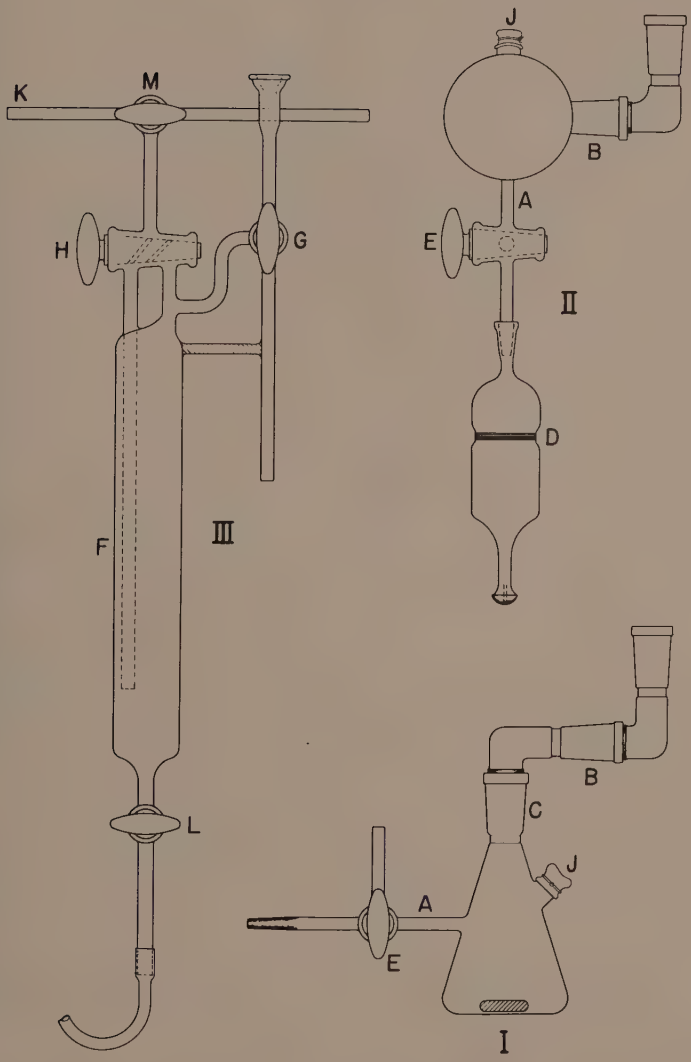
B. The Quantitative Oxygenation of Vitamin B_{12r}

Procedure.

Following the hydrogenation of B_{12}, the residual brown solution was filtered to remove the platinum catalyst and treated with oxygen in such a manner that the oxygen uptake could be measured (Fig. 1). The hydrogenation flask was tilted up so that the solution could be drained through the side arm A; this was accomplished without disconnecting the flask from the hydrogenation apparatus by two 90° rotations about the joints B and C, (Figs. I, II). The chamber F was filled with mercury so that by opening stopcocks E and G with H closed, the B_{12r} solution could be drawn through the fritted glass filter D. A hypodermic needle was then inserted through the rubber plug J in the hydrogenation flask and a stream of water injected to wash down the walls of the hydrogenation flask and the connecting tubing.

A buret containing oxygen was attached at K. Oxygen was bubbled through the solution by properly opening L, M, H, and G. The oxygen was then taken back to the buret by reversing H. Oxygen was bubbled through the solution several times in this manner. Finally the change in volume of the oxygen was measured and the residual oxygen and evolved gases transferred to an Orsat apparatus. The carbon dioxide, oxygen, unsaturated hydrocarbons and carbon monoxide were absorbed and measured in the usual manner. Unfortunately, the Orsat apparatus was not provided with combustion units by which the hydrogen and saturated hydrocarbons could be determined.

Following separation from the oxygen and evolved gases, the solution of B_{12a} was treated with 1 g. of potassium cyanide dissolved in 5 ml. of water. The solution was added without introducing any air into the apparatus. Over a period of twelve hours no gas was liberated. The pH of the solution was then adjusted to 7 with sulfuric acid and flushed with a stream of filtered air for two hours to sweep out hydrogen cyanide. An aliquot of this solution was suitably diluted and its absorption spectrum obtained.



Figs. I, II, III. Apparatus for treating hydrogenated vitamon B_{12} with Oxygen.

Results

The oxygenation of the B_{12r} solution from only the second hydrogenation experiment was studied quantitatively. Oxygen, starting with a volume of 100 ml., was passed through the B_{12r} solution thirteen times, the decrease in volume on each of the last four passes amounted to less than 0.1 ml. or was not detectable. The total decrease in volume observed was 18.5 ml. The residual gas was found to consist of 4.43 ml. of carbon monoxide, 67.1 ml. of oxygen, and 11.1 ml. of unabsorbed gas, definitely not carbon dioxide, carbon monoxide, oxygen, or unsaturated hydrocarbon, but possibly hydrogen, saturated hydrocarbon or nitrogen.

The oxygen consumed calculated by adding to the observed contraction in volume, the volume of carbon monoxide, and unidentified gas produced totaled 34.0 ml.; calculated by subtracting the residual oxygen from the initial 100 ml. it totaled 32.9 ml. Reducing the 34.0 figure to standard conditions and conversion to atoms of oxygen, gave 3.66 atoms of oxygen per molecule of B_{12}. The carbon monoxide formed amounted to 0.23 moles per mole of B_{12}. The volume of unidentified gas corresponded to 0.60 moles per mole of B_{12}.

Inasmuch as only one-half an atom of oxygen would be required to oxidize the cobalt from two to three, it is apparent that a considerable amount of oxygen is used for other reactions. It is conceivable that molecular oxygen adds to the cobalt atom in the manner in which it adds to disalicylalethylenediimine cobalt (1). This prompted the final part of the experiment in which the oxygenated solution was treated with cyanide. No gas was liberated as would have been expected if cyanide displaced molecular oxygen from the cobalt. It is not safe, however, to conclude that attached molecular oxygen was not present, for B_{12a} is a good catalyst for certain oxidation reactions, and a catalytic oxidation of cyanide might well have occurred disallowing the evolution of any oxygen.

In any case, the action of oxygen on B_{12r} causes some oxidation of the molecule as evidenced by the formation of carbon monoxide and some other gas. This explains the low yield of B_{12a} obtained in the hydrogenation-oxygenation of B_{12}. In spite of the changes which must take place in the molecule as a result of these operations, the material after treatment with cyanide has the same absorption spectrum as vitamin B_{12}.

C. Chemical Changes During the Hydrogenation of Vitamin B_{12}

Apparatus, reagents, and procedure.

The hydrogenation was carried out in the apparatus described in an earlier paper (2).

The hydrogen was purified by passage through alkaline permanganate, vanadous sulfate, ascarite, and anhydrous magnesium perchlorate.

Experiment 1. Base liberated during hydrogenation.

The hydrogenation was carried out in a cell bearing side arms to accommodate glass and saturated calomel electrodes. Ten ml. of a solution containing 1 mg. of B_{12} per ml. was hydrogenated over platinum catalyst.

An increase in pH was observed as the hydrogenation progressed 0 hrs., 7.25 pH, 0.5 hrs., 8.7 pH, and 7 hrs., 10.1 pH. During the

first 1.5 hours the color of the solution changed from red to orange-red becoming brown only after this time. It is evident, therefore, that the reduction of cyanide preceded the reductions of the cobalt for the most part.

Experiment 2. Absence of hydrogen cyanide and methylamine in the hydrogen discharge.

The hydrogenation was carried out as in Experiment 1, the hydrogen leaving the apparatus being bubbled through a trap containing standard silver nitrate. After the hydrogenation was completed, the silver nitrate was made alkaline with ammonium hydroxide, a known excess of standard cyanide and a crystal of potassium iodide were added, and the solution was titrated with standard silver nitrate. No hydrogen cyanide was collected in the trap and the same result was obtained in several repetitions of the experiment.

In other hydrogenations, the effluent hydrogen was bubbled through a trap containing standard acid which was later back titrated with standard base.

No base was carried over in the hydrogen stream. Working with a known amount of methylamine, it was shown that methylamine is not swept out of solution by a stream of hydrogen.

Experiment 3. Quantitative titration of the base liberated on hydrogenation.

Vitamin B_{12} was hydrogenated for ten hours, the platinum filtered off (without exposing the solution to the atmosphere at any time), and the resulting solution titrated with 0.00215 N standard hydrochloric acid. A glass electrode, saturated calomel electrode, and Backman model G pH meter were used for the titrations.

The results of four such titrations are shown in Table 2 under "First titration".

Table 2. Titration of base liberated on hydrogenation of vitamin B_{12} and on oxygenation of B_{12r}.

	First titration			Second titration	
Co present (millieq.)	HCl required (millieq.)	End-point (pH)	HCl/Co	HCl required (millieq.)	HCl/Co
a) 0.00952	0.00968	- -	1.1015	- -	- -
b) 0.01145	0.01107	7.1	0.935	0.0204	1.78
c) 0.02490	0.02580	4.8	1.045	0.0495	1.98
d) 0.01420	- -	(10.1)	- -	0.0237	1.67

Experiment 4. Base formed on oxygenation of B_{12r}. (Titration of B_{12a}).

Following the hydrogenation of B_{12} and the titration of the base formed, carbon dioxide-free air was passed through the solution. The solution was then again titrated potentiometrically with standard acid. The first titration was stopped and oxygenation made at pH 7.1 (titration b), at 4.8

(titration c), and at 10.1 (titration d) directly following hydrogenation.

The vitamin B_{12a} produced by oxidation required one equivalent of hydrochloric acid (Table 2) with somewhat less required when the oxygenation was performed at higher pH.

Experiment 5. Methylamine formed during hydrogenation.

To the solution resulting from hydrogenation and oxygenation was added methanol and picric acid. After heating for 15 minutes, the mixture was cooled and the precipitate which formed filtered off. M.p.: 209-215°; m.p. of authentic methylamine picrate: 207°; mixed m.p.: 208-214°.

To the solution resulting from hydrogenation and oxygenation was added sodium hydroxide and p-toluenesulfonyl chloride. The solution was acidified, cooled in a salt-ice mixture and the crystals which formed removed. M.p.: 72-75°; m.p. authentic p-toluenesulfonmethyl amide: 75°; mixed m.p.: 72-77°.

CONCLUSIONS

The hydrogenation of vitamin B_{12} proceeds with the absorption of 2.5 molecules of hydrogen, the cyanide being reduced to methylamine and the cobalt to a valence of two:

$$RCo(III)CN + 5/2H_2 = RCo(II) + CH_3NH_2$$

Although one equivalent of base is formed in the oxygenation of the resulting B_{12r}

$$2RCo(II) + 1/2O_2 + H_2O = 2RCoOH$$

the oxygenation is not this simple for two molecules of oxygen are absorbed and carbon monoxide and at least one other gas are liberated. The yield of B_{12a} in the hydrogenation-oxygenation operation is therefore low.

ACKNOWLEDGEMENT

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REFERENCES

1. Diehl, H. Studies on oxygen-carrying cobalt compounds. Iowa State Coll. Jour. Sci. 21:271. 1947.
2. _____, and R. Murie. On the properties of vitamin B_{12r}. Iowa State Coll. Jour. Sci. 26:555. 1952.
3. Kaczka, E., E.E. Wolf, and K. Folkers. Vitamin B_{12}. V. Identification of crystalline vitamin B_{12a}. Jour. Amer. Chem. Soc. 71: 1514. 1949.

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THE DISTRIBUTION OF NITROGEN IN THE MOLECULE OF VITAMIN B_{12}

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Hydrochloric acid hydrolysis of vitamin B_{12} has yielded 5,6-dimethylbenzimidazole (3,4), ribose (5), phosphoric acid (9, 16), 1-amino-2-propanol (11, 12, 19), ammonia (17), cyanide (6), and a red, acid fragment (15). Application of the Van Slyke amino nitrogen method has shown the absence of primary amine groups (14) and the presence of five amide groups (13); the presence of amide groups has been confirmed (2). A quantitative study of the hydrochloric acid hydrolysis products of vitamin B_{12} using the Craig countercurrent distribution technique led to a definitive allocation of the nitrogen atoms in the molecule.

EXPERIMENTAL WORK

Materials. Vitamin B_{12}, obtained from the Squibb Institute for Medical Research, New Brunswick, New Jersey, was recrystallized from water. The absorption spectrum was identical with that reported for B_{12} (7).

Vitamin B_{12a} was prepared by hydrogenation of recrystallized B_{12}, oxidation by air, and crystallization by the addition of acetone (18). Found: N 13.03, 13.20, 13.48 (Dumas, E.W.D. Huffman), 13.37 (Dumas, J. Alicino), Ave. 13.27; Co 4.24, 4.30 (colorimetric following digestion with perchloric acid, J.L.E.), 4.26 (same, J.M.B.), 4.42 ($CoSo_4$ residue, J. Alicino), Ave. 4.30. N:Co = 13.07. All analyses were made on the same lot of material and all after drying at 80° in a vacuum for four hours.

Separation and determination of ammonia and 1-amino-2-propanol. Mixtures prepared from standard solutions of ammonium chloride and 1-amino-2-propanol (b.p. 159-160°) showed that distillation for exactly 5 minutes in the Parnas micro Kjeldahl apparatus at pH 8, phosphate buffer, yielded only ammonia. At seven minutes a detectable amount of 1-amino-2-propanol distilled. Following distillation of ammonia, the residual solution was acidified and treated with excess periodic acid. The ammonia liberated was then distilled and titrated. The method does not, of course, distinguish 1-amino-2-propanol from ethanolamine or other 1,2-aminoalcohols.

Quantitative determination of the products of acid hydrolysis. Vitamin B_{12a} was placed in a round bottom flask equipped with a gas inlet tube, dropping funnel, and reflux condenser. To the top of the reflux condenser was connected successively a trap containing silver nitrate solution, a U-tube containing anhydrous magnesium perchlorate, and a Turner bulb containing ascarite followed by anhydrous magnesium perchlorate. Air in the apparatus was displaced by the passage through the apparatus for three hours of nitrogen purified by passage over acid vanadous sulfate,

ascarite, and anhydrous magnesium perchlorate. The Turner bulb was then weighed. Sufficient deaerated 11.6 M hydrochloric acid was then added to make the mixture 1.00 M in hydrochloric acid. The mixture was then heated and maintained at 100° for 22 hours with a slow stream of nitrogen passing. The ascarite tube was again weighed.

Following hydrolysis the solution was diluted with water in a volumetric flask and aliquots taken for the determination of cobalt and ammonia. The solution was then evaporated to dryness in a vacuum over anhydrous magnesium perchlorate and solid sodium hydroxide. The residue was then dissolved in 1 M hydrochloric acid previously equilibrated with isobutyl alcohol. This solution was extracted countercurrently in a glass Craig apparatus with isobutyl alcohol previously equilibrated with 1 M hydrochloric acid. After forty transfers, the liquids in each of the tubes were rendered miscible with ethanol, diluted in volumetric flasks and then analyzed for total nitrogen, ammonia, cobalt, benzimidazole, red acid fragment, and phosphorus. In addition, tubes 0 through 15 were analyzed for free phosphate and tubes 0 through 6 for 1,2-aminoalcohols.

Infrared spectra. Infrared spectra of B_{12} and of the red, acid fragment were obtained in the form of Nujol mulls using a Baird double-beam, recording spectrograph.

Mercurated B_{12}. Fifty mg. of B_{12} were dissolved in 20 ml. of 95 per cent ethanol. Fifteen ml. of an alcoholic solution of 36.0 mg. of mercuric acetate and 3 drops of glacial acetic acid were added with stirring. After 5 hours, a drop of 1 N sodium hydroxide was added. The red, amorphous precipitate was removed by centrifuging and washed with alcohol. This material was readily soluble in dilute sulfuric acid with the liberation of mercuric ions. The infrared spectrum, obtained as a Nujol mull, was practically identical with that of B_{12} except in the region 6.0 to 6.3μ where the amide bands were considerably modified. Analyses for cobalt and mercury gave a value of 2.82 for the mercury to cobalt ratio. Attempts to crystallize the mercurated product failed, including one attempt to raise the pH slowly by the diffusion of trimethylamine into an aqueous solution of the material.

RESULTS

The analyses made on the carefully purified specimen of B_{12a} definitely establish the nitrogen-cobalt ratio as thirteen and by implication also the nitrogen-cobalt ratio of B_{12} as fourteen (addition of one cyanide). This result has been anticipated by Alicino's analysis (1) of $B_{12}.6HClO_4$. The molecular weight calculated on the basis of the cobalt analyses here reported is 1370; this is probably a better value than others reported earlier as the colorimetric cobalt determination is more reliable than the gravimetric sulfate method which suffers from incomplete elimination of phosphate and from the presence of silica and other nonvolatile material.

Primary amino groups have been shown to be absent from B_{12} and B_{12a} (14). The result of the Van Slyke-Plimer analysis indicates the presence of five acid amide groups. These are then the source of the five ammonia molecules liberated on acid hydrolysis (see below). In agreement with this, the infrared spectrum of B_{12} shows strong absorption bands at 6.05μ and a shoulder at 6.20μ which are not present in the spectrum of the red,

acid fragment. On the other hand, the red fragment has bands at 5.60 and 5.80 μ indicating free carboxyl groups with some anhydride formation. No absorption of B_{12} occurs between 5.5 and 6.0 μ ; the presence of lactams is thus ruled out. The formation of mercurated B_{12} containing 2.8 mercury atoms per cobalt is about that expected for a material containing five amide groups.

Vitamin B_{12a} rather than B_{12} was selected for the quantitative hydrolysis study to avoid the ambiguity which arises from the hydrolysis of cyanide, for during hydrochloric acid hydrolysis the latter passes off as hydrogen cyanide in part and is hydrolyzed to formaide or to ammonium formate in part. The hydrolysis was carried out in the absence of oxygen to avoid catalytic oxidation effects of B_{12a} (8).

No carbon dioxide was evolved during the hydrochloric acid hydrolysis of B_{12a}. Ureide and similar groups are therefore absent.

The overall results of the 40-transfer distribution of the hydrochloric acid hydrolysis products of B_{12a} between isobutyl alcohol and 1 M hydrochloric acid were:

1. Sufficient separation of the nitrogen-bearing products was obtained that, when coupled with suitable analytical methods, a definite allocation of the various nitrogen atoms became possible.

2. The red fragment moved rapidly, concentrating for the most part in tubes 37 through 40, but with minor amounts of brownish material remaining in tubes 0 through 36.

3. The benzimidazole concentrated in tubes 11 through 25 as evidenced by the absorption of 278 mμ and by the maximum in the total nitrogen analysis occurring at tube 15.

4. Ammonia remained in tubes 0 through 5.

5. The 1-amino-2-propanol distributed in tubes 0 through 6 as shown by both the difference between the ammonia and total nitrogen values and by the periodate oxidation analysis for 1,2-aminoalcohols.

6. For the most part the cobalt accompanied the red fragment but some 8 per cent of the total was found in the first tubes as free cobalt.

7. The major part of the phosphorus accompanied the benzimidazole, tubes 8 through 23, but 15 per cent of it was found as free phosphoric acid in tubes 0 through 7 and some 6 per cent accompanied the red fragment into tubes 37 through 40. That free phosphoric acid was present in tubes 0 through 7 was shown by direct phosphate determination without digestion and by a determination of the distribution coefficient of phosphoric acid in the solvent system employed. The maximum of the Craig distribution of a material with this distribution coefficient (0.14) occurs in tube 5, where it was found experimentally. The phosphorus which accompanied the red fragment benzimidazole was bound phosphorus.

Fig. 1. Craig distribution of the hydrochloric acid hydrolysis products of vitamin B_{12a}. 501.3 mg. B_{12a} (8.95 per cent water), 1.0 M hydrochloric acid, 100°, 22 hours. Distribution system: isobutanol-1 M hydrochloric acid.

——— Total nitrogen determined by Kjeldahl (total recovery: 97.3 per cent).

——— Cobalt determined colorimetrically following perchloric acid digestion (total recovery: 97:4 per cent).

- - - - - Benzimidazole as measured by absorbency at 278 mμ (concentration assumed to be directly proportional to absorbency).

— — Red, acid fragment as measured by absorbency at 346 mμ (concentration assumed to be directly proportional to absorbency).

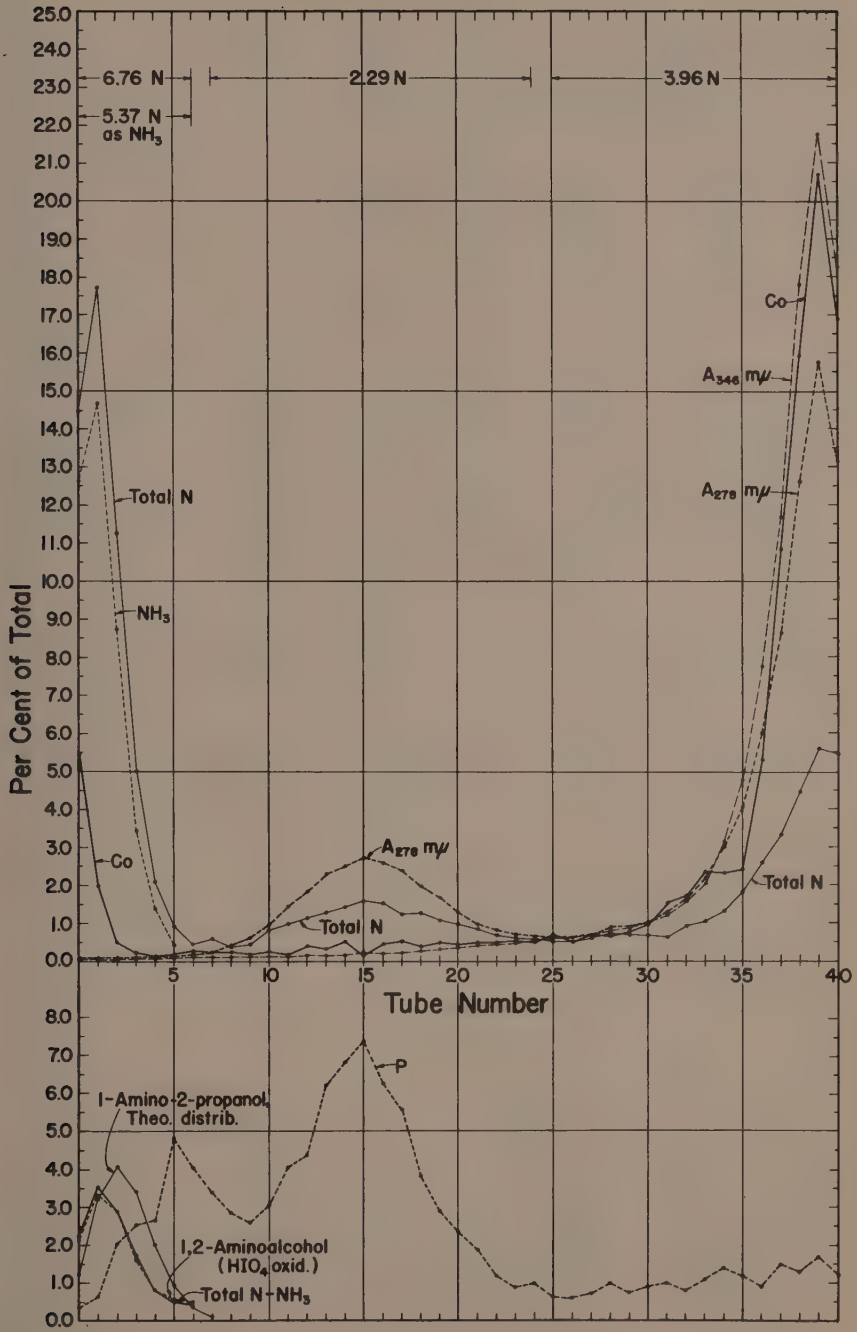
– – – – Ammonia determined by 5 minute distillation (pH 8, phosphate buffer) and titration (total recovery 41.4 per cent of the total nitrogen in all tubes).

——— Total nitrogen minus ammonia nitrogen, presumably 1-amino-2-propanol.

– – – – 1,2-aminoalcohols as determined periodate oxidation-distillation-titration method.

——— 1-amino-2-propanol, theoretical distribution.

- - - - - Phosphorus determined colorimetrically following perchloric acid digestion (total recovery: 103 per cent). Inorganic phosphate, tubes 0 through 6 identical with total phosphorus.


6.76 N
5.37 N as NH3
2.29 N
3.96 N
Co
A346 mμ
A278 mμ
Total N
NH3
Per Cent of Total
Co
A278 mμ
Total N
Total N
Tube Number
P
1-Amino-2-propanol, Theo. distrib.
1,2-Aminoalcohol (HIO4 oxid.)
Total N-NH3

It is somewhat arbitrary where the cuts are made between the various fractions but quite clearly the different types of nitrogen can be distributed and the numbers of their atoms established.

Tubes 25 through 40 contained 30.5 per cent of the total nitrogen corresponding to 3.96 of the thirteen nitrogen atoms of the molecule. The inclusion of two or three tubes one way or another in the calculation changes the value from 3.96 by less than 0.2.

Of the total nitrogen, 17.6 per cent fell in tubes 7 through 24. This corresponds to 2.29 nitrogen atoms. The benzimidazole bears two nitrogen atoms so a little extra nitrogen was carried into this region.

The ammonia nitrogen, tubes 0 through 6, amounted to 5.37 moles of nitrogen as calculated by dividing the ammonia nitrogen by the total nitrogen in all tubes and multiplying by 12. As shown by the analysis of known mixtures, the distillation method tends toward high results for ammonia and the number of ammonia molecules formed is undoubtedly five. Five ammonia would be expected from the hydrolysis of five amide groups (13).

Calculated as the difference between total Kjeldahl nitrogen and ammonia nitrogen, 12.1 per cent of the total nitrogen fell in tubes 0 through 6; this corresponds to 1.57 atoms of nitrogen. Calculated from the periodate-ammonia determination 11.8 per cent of the nitrogen fell in these same tubes, corresponding to 1.53 nitrogen atoms. The amount of 1-amino-2-propanol, or strictly of 1,2-aminoalcohol, is thus short of two. This discrepancy is probably a combination of two factors: incomplete separation of ammonia and aminoalcohol in the distillation process, and carry-over of aminoalcohol into the benzimidazole region, perhaps as a compound with the aminoalcohol still attached to the benzimidazole-bearing fragments. The excess ammonia above 5 and benzimidazole above 2 if added to the aminoalcohol bring the value fo 2.23. The agreement between the experimental and the theoretical distribution curves for 1-amino-2-propanol (distribution coefficient 0.065, 0.077, 0.080, Ave. 0.074) is not exact (Fig. 1) but is close enough to support the interpretation just presented. Probably both nitrogen atoms are derived from 1-amino-2-propanol in agreement with the finding of Chargaff and co-workers (10) and contrary to the results of the British Drug Houses group (11), although the possibility of one molecule of 1-amino-2-propanol and one of another 1,2-amino-alcohol is not excluded by the present work.

The thirteen nitrogen atoms of B_{12a} are thus distributed as follows:

1 5,6-dimethylbenzimidazole	2 nitrogen atoms
2 1,2-aminoalcohols (both 1-amino-2-propanol?)	2
5 acid amide	5
1 red, acid fragment	4
	13

Tubes 25 to 40 contained only 84.3 per cent of the cobalt. Inasmuch as these tubes contained nitrogen corresponding to 3.96 nitrogen atoms, it is apparent that about 15 per cent of the red acid fragment has been stripped of its cobalt. Of the remaining cobalt, 8.17 per cent was present in tubes 0 through 4; this was present as cobaltous ion as shown by direct colorimetric measurement. Some 7 per cent of the cobalt fell in tubes 5 through 24 as brownish cobalt compounds, quite possibly as derivatives

Table 1. Separation and determination of ammonia and 1-amino-2-propanol.

Ammonia		1-Amino-2-propanol	
Taken (mg.)	Found (mg.)	Taken (mg.)	Found (mg.)
0.171	0.182	0.903	- -*
0.171	0.176	0.903	- -*
0.171	0.179	0.903	0.887
0.171	0.173	0.903	0.864

*Not determined.

of the benzimidazole fragments. The presence of cobaltous ion and of phosphate in the first tubes and of phosphorus in the tubes containing the red fragment explain the difficulties which have been encountered in purifying the red fragment. Coupled with anhydride formation and with variation in the nature of the groups occupying the remaining coordination positions about the cobalt atom, the mixture is indeed a formidable one to separate.

SUMMARY

Application of the Plimmer modification of the Van Slyke amino nitrogen determination has shown the presence of five amide groups in vitamin B_{12}. A quantitative determination of the hydrolysis products of vitamin B_{12} has shown that five molecules of ammonia are liberated, that two nitrogen atoms are present in a form which does not yield ammonia on acid hydrolysis but does yield ammonia on treatment with periodic acid (one or both possibly 1,2-aminoalcohol), and that the nitrogen to cobalt ratio in the red acidic fragment is four.

ACKNOWLEDGEMENT

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REFERENCES

1. Alicino, J. Perchloric acid salt of vitamin B_{12}. Jour. Amer. Chem. Soc. 73:4051. 1951.
2. Armitage, J.B., J.R. Cannon, A.W. Johnson, L.F.J. Parker, E.L. Smith, W.H. Stafford, and A.R. Todd. Chemistry of the vitamin B_{12} group. Part III. The course of hydrolytic degradations. Jour. Chem. Soc. 1953:3849.
3. Beaven, G.R., E.R. Holiday, E.A. Johnson, B. Ellis, P. Mamalis, V. Petrow, and B. Sturgeon, The chemistry of anti-pernicious anaemia factors. Part III. 5 : 6-disubstituted benzimidazoles as products of acid hydrolysis of vitamin B_{12}. Jour. Pharm. Pharmacol. 1:97. 1949.

4. Brink, N.G., and K. Folkers. Vitamin B_{12}. VI. 5,6-Dimethylbenzimidazole, a degradation product of vitamin B_{12}. Jour. Amer. Chem. Soc. 71:2951. 1949.
5. _____, F.W. Holly, C.H. Shunk, E.W. Peel, J.J. Cahill, and K. Folkers. Vitamin B_{12}. IX. 1-D-Ribofuranosido-5,6-dimethylbenzimidazole, a degradation product of vitamin B_{12}. Jour. Amer. Chem. Soc. 72:1866. 1950.
6. _____, F.A. Kuehl, Jr., and K. Folkers. Vitamin B_{12}: the identification of vitamin B_{12} as a cyano-cobalt coordination complex. Science 112:354. 1950.
7. _____, D.E. Wolk, E. Kaczka, E.L. Rickes, F.R. Koniuszy, T.R. Wood, and K. Folkers. Vitamin B_{12}. IV. Further characterization of vitamin B_{12}. Jour. Amer. Chem. Soc. 71:1854. 1949.
8. Brierly, J.M., J.L. Ellingboe, and H. Diehl. Catalytic behavior of vitamin B_{12a} in the oxidation of iodide by air. Iowa State Coll. Jour. Sci. 27:425. 1953.
9. Buchanan, J.G., A.W. Johnson, J.A. Mills, and A.R. Todd. Chemistry of the vitamin B_{12} group. Part I. Acid hydrolysis studies. Isolation of a phosphorus-containing degradation product. Jour. Chem. Soc. 1950:2845.
10. Chargaff, E., C. Levine, C. Green, and J. Kream. Study of some constituents of vitamin B_{12}. Experientia 6:229. 1950.
11. Cooley, G., M.T. Davies, B. Ellis, V. Petrow, and B. Sturgeon. The chemistry of anti-pernicious anaemia factors. Part XII. The 1-aminopropan-2-ol component of cyanocobalamin. Jour. Pharm. Pharmacol. 5:257. 1953.
12. _____, B. Ellis, and V. Petrow. Further observations on the "ninhydrin-reacting" hydrolytic fragment of vitamin B_{12}. Jour. Pharm. Pharmacol. 2:128. 1950.
13. Diehl, H., and J.L. Ellingboe. Determination of amide nitrogen in vitamins B_{12} and B_{12a}. Iowa State Coll. Jour. Sci. 27:421. 1953.
14. _____, and J.I. Morrison. Determination of amino nitrogen in vitamins B_{12} and B_{12a}. Iowa State Coll. Jour. Sci. 26:589. 1952.
15. Ellis, B., V. Petrow, and G.F. Snook. The isolation of the crystalline anti-pernicious anaemia factor from liver. Jour. Pharm. Pharmacol. 1:60. 1949.
16. _____, _____, _____. The chemistry of anti-pernicious anaemia factors. Part I. The liberation of phosphorus as phosphate from vitamin B_{12} by acid hydrolysis. Jour. Pharm. Pharmacol. 1:287. 1949.
17. _____, _____, _____. The chemistry of anti-pernicious anaemia factors. Part II. The "ninhydrin-reacting" hydrolytic fragment of vitamin B_{12}. Jour. Pharm. Pharmacol. 1:950. 1949.
18. Kaczka, E., D.E. Wolf, and K. Folkers. Vitamin B_{12}. V. Identification of crystalline vitamin B_{12a}. Jour. Amer. Chem. Soc. 71: 1514. 1949.
19. Wolf, D.E., W.H. Jones, J. Valiant, and K. Folkers. Vitamin B_{12} XI. Degradation of vitamin B_{12} to Dg-1-amino-2-propanol. Jour. Amer. Chem. Soc. 72:2820. 1950.

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DETECTION OF CHERRY VIRUS IN PRUNUS MAHALEB[1]

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Of immediate practical concern in nursery production of virus-free sour cherry trees is assurance of freedom from virus in Prunus mahaleb understock seedlings. Satisfactory detection of virus in fairly large samples of such seedlings would be possible with a readily propagated plant which expresses definite symptoms at a range of temperatures when grafted with virus-infected buds of P. mahaleb.

An unusually convenient indexing method, if feasible, would be to use the P. mahaleb seedlings themselves, in a manner similar to the "indirect" method of Moore and Keitt (4) with cherries. For P. mahaleb to be so usuable, it would need to exhibit very distinct virus latency plus a similarly distinct cross protection among a wide range of virus sources. It would also need to express distinct symptoms when first infected with virus – before latency.

Experiments reported in this paper definitely point to failure of P. mahaleb to express any symptoms reliably at high greenhouse temperatures and to lack of virus latency in it at temperatures favorable to symptom expression. P. tomentosa, on the other hand, reliably expressed symptoms when budded with virus-infected P. mahaleb buds, and when budded with virus-infected cherry buds, expressed symptoms at each of three greenhouse temperatures.

Pertinent Previous Information

Suitability of P. tomentosa as an index plant for cherry viruses capable of inducing necrotic ring spot has been reported by Fink (1). His comparisons were of P. tomentosa with virus-free sour cherry, P. cerasus, and to a limited extent with peach, P. persicae. Fridlund recently reported (2) that in comparisons with Montmorency sour cherry, peach, and Kwanzan and Shirofugan varieties of flowering cherry (P. serrulata), P. tomentosa was a satisfactory index plant for necrotic ring spot virus.

The "indirect" method reported by Moore and Keitt (4) for detection of necrotic ring spot virus in cherry involves inoculating an "unknown" tree with virus. Subsequent expression of symptoms indicates initial freedom from virus in the unknown; conversely, failure of symptom expression indicates initial presence of virus. This pattern of behavior is based on the phenomena of latency and cross protection, which are distinct in cherry.

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[1]Journal paper No. J-2672 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 1060. Taken from a thesis submitted by the first author to the graduate faculty at Iowa State College, for the degree, Doctor of Philosophy.

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According to experiments reported by Moore and Keitt (3), necrotic ring spot symptoms were expressed by inoculated sour cherries kept at constant greenhouse temperatures of from 16° to 28°C, but more rapidly and with more necrosis at the higher temperatures. High greenhouse temperatures were likewise favorable to symptom expression by P. pumila, P. virginiana, P. americana, and P. besseyi.

EXPERIMENTS

The data to be presented were accumulated from two experiments. One involved a series of potted P. mahaleb seedlings which were, in order: (a) indexed on P. tomentosa to insure initial freedom from virus; (b) inoculated with virus and incubated at one of three greenhouse temperatures and observed for symptom expression; (c) set in the field to oversummer and become dormant, and heeled in until mid-winter; (d) again indexed on P. tomentosa, and (e) again inoculated with virus and observed for symptom expression. Step (b) enabled a determination of extent of symptom expression by P. mahaleb at greenhouse temperatures of 60°, 70°, and 80°F (Table 2). Step (d) yielded an evaluation of validity of indexing for virus in P. mahaleb on P. tomentosa. Step (e) provided evidence of lack of cherry virus latency in P. mahaleb (Table 3).

The second experiment involved a series of potted P. tomentosa seedlings which were inoculated with virus and incubated in the greenhouse at 60°, 70°, or 80°F, and indicated satisfactory expression of symptoms at all three temperatures (Table 4).

Virus sources used in the two experiments are listed, with descriptions, in Table 1. All were supplied by Dr. J.D. Moore, University of Wisconsin.

RESULTS

Symptom Expression by P. mahaleb at Three Greenhouse Temperatures

Nine P. mahaleb seedling trees were inoculated with each source of virus; 14 sources and 126 seedlings altogether. There were nine uninoculated check seedlings. For each virus source and the uninoculated check, three seedlings were incubated in a 60° greenhouse, three in a 70° greenhouse and three in an 80°F greenhouse. All were observed periodically for symptom development.

Foliation and growth were rapid in the greenhouse maintained at 80°F, but in no case were any symptoms observed at that temperature (Table 2). Much the same situation prevailed at 70°F, except that there was definite mottling of leaf lamina on two of three seedling trees inoculated with virus sources B-1-12 and B-3-22, and very mild leaf mottling on two of three seedlings inoculated with source B-1-4 and on two of three seedlings with source G-20-5.

All trees in the 60°F greenhouse exhibited definite but variable symptoms, except for one of three trees inoculated with virus source G-2-1, one of three with source M-3-17, one of three with source M-7-74, and one with source G-2-7. These all exhibited mild or questionable symptoms. Even at 60°F, symptom expression by P. mahaleb was not as striking as is usual on P. tomentosa or sour cherry. Typical examples of leaves from plants at the three temperatures are shown in Fig. 1.

Table 1. Descriptions of virus sources used to inoculate P. mahaleb and P. tomentosa.

Virus source	Description
B-1-12	Necrotic ring spot
G-2-1	Necrotic ring spot
G-5-1	Necrotic ring spot
B-1-4	Necrotic ring spot and yellows
B-3-23	Necrotic ring spot and yellows
M-3-17	Necrotic ring spot and yellows
Local	Necrotic ring spot and yellows
M-7-74	Necrotic ring spot and yellows (mild)
B-3-22	Necrotic ring spot, yellows, and prune dwarf
G-2-7	Necrotic ring spot, yellows, and prune dwarf
G-20-5	Necrotic ring spot, yellows, and prune dwarf
G-17-4	Necrotic ring spot, yellows, and green ring mottle
M-5-74	Necrotic ring spot, yellows, and green ring mottle
M-6-19	Necrotic ring spot and yellows (recurrent)
S-5009	Necrotic ring spot and yellows (recurrent

Fig. 1. Symptoms of P. mahaleb at three temperatures; virus source M-5-74. From left to right, both top and bottom rows; leaves from uninoculated check, leaves from inoculated trees at 60°, 70°, and 80°F, respectively.

Table 2. Symptom expression by P. mahaleb seedlings inoculated with 14 sources of necrotic ring spot virus and held at three greenhouse temperatures.

Virus source	Greenhouse temperature °F	Seedlings with symptoms classed as: severe	moderate	mild or questionable	none
B-1-12	60	2	1		
	70		2	1	
	80				3
G-5-1	60	1	2		
	70				3
	80				3
G-2-1	60		2	1	
	70				3
	80				3
B-3-23	60		3		
	70				3
	80				3
B-1-4	60	3			
	70			2	1
	80				3
M-3-17	60	1	1	1	
	70				3
	80				3
M-7-74	60		2	1	
	70				3
	80				3
B-3-22	60	3			
	70		2	1	
	80				3
G-20-5	60	1	2		
	70			2	1
	80				3
G-2-7	60		2	1	
	70				3
	80				3
M-5-74	60	1	2		
	70				3
	80				3
G-17-4	60		3		
	70				3
	80				3
M-6-9	60	3			
	70				3
	80				3
S-5009	60	2	1		
	70				3
	80				3
Uninoculated (check)	60				3
	70				3
	80				3

Index of Infected P. mahaleb on P. tomentosa

After having been set in the field for the summer and heeled in during the fall, the previously inoculated P. mahaleb seedlings, and checks, were indexed on P. tomentosa. Two buds from what appeared to be a live, dormant twig of each P. mahaleb tree were chip-grafted to a potted P. tomentosa seedling at bud break. Observations were made regularly for symptoms on growth following inoculation.

Buds from all the uninoculated check P. mahaleb trees failed to induce symptoms on P. tomentosa. Of the 126 P. mahaleb trees previously inoculated with virus, 102 indexed as diseased. Of the 24 P. tomentosa without symptoms, three died before symptoms could have been expressed and bud graft union was definitely unsuccessful on nine others. Under the circumstances of this experiment, then, presence of virus was not detected in 12 of the 126 previously inoculated P. mahaleb trees, four of which expressed symptoms in the next step of the experiment.

Although difficult to reduce to terms of specific data, it was evident that in this instance union of P. mahaleb with the P. tomentosa scions was not as complete as is usual with sour cherry buds. It may be pertinent that when the P. mahaleb trees later were brought into the greenhouse, 54 of the original 135 failed to start growth or died soon after growth began, including two uninoculated check trees. The condition of the P. mahaleb trees may have been a factor in the only nominally successful bud unions on P. tomentosa and perhaps in the 12 failures of virus detection on P. tomentosa. However, symptoms when expressed on P. tomentosa were distinct, and it would appear to be a fairly satisfactory index plant for detection of virus in P. mahaleb.

It should be pointed out that the above positive evidence of presence of virus in 102 of the P. mahaleb trees a year after inoculation shows that failure to express symptoms at 70° and 80° F (when incubated after inoculation) was not attributable to lack of virus in trees at those temperatures. Furthermore, it was evident that virus was present in the P. mahaleb trees at the beginning of the next and last step in the experiment.

Latency and Cross Protection in P. mahaleb

The P. mahaleb trees which had been inoculated with virus and incubated at three temperatures, over-summered in the field, heeled in, and indexed on P. tomentosa, as recorded above, next were brought in the greenhouse and a portion of them reinoculated with virus. The basic plan was to reinoculate three of the nine trees originally inoculated with one source of virus with another similar source (i.e., if the original source was one which induces necrotic ring spot only on sour cherry, then the "similar" source was one which does likewise). Three more of the nine trees were to be reinoculated with a dissimilar source (i.e., a source which induces yellows in addition to necrotic ring spot on sour cherry). The three remaining trees were not to be reinoculated. Insofar as living trees were available, the plan was followed, but as recorded above, only 81 of the original 135 trees were alive and growing at the end of the experiment. After the designated trees had been reinoculated at time of bud break, all 81 trees were incubated in a greenhouse maintained at

Table 3. Symptom expression in 1954 by P. mahaleb trees inoculated in 1953 and reinoculated with virus in 1954.

Virus source		No. of trees	Trees with symptoms classed as:			
1953	1954	in 1954	severe	moderate	questionable	none
B-1-12	G-5-1	1		1		
	B-3-22	3	1	2		
	None	1			1	
G-5-1	B-1-12	2	1			1*
	B-3-22	2		2		
G-2-1	B-1-12	1		1		
	B-3-22	3		2		1*
	None	1		1		
B-3-23	B-1-12	2		1	1	
	B-3-22	2		2		
	None	1		1		
B-1-4	B-1-12	2		2		
	B-3-22	1		1		
M-3-17	B-1-12	2			1	1*
	B-3-22	2		1	1	
	None	1		1		
M-7-74	B-1-12	3		1	2	
	B-3-22	2		2		
	None	2		1	1	
B-3-22	B-1-12	3	1	2		
	G-20-5	3		3		
	None	2		2		
G-20-5	B-1-12	1		1		
	B-3-22	2		2		
	None	1		1		
G-2-7	B-1-12	3		2	1*	
	B-3-22	3		3		
	None	1		1		
M-5-74	B-1-12	2		2		
	G-17-4	3		3		
	None	1				1
G-17-4	B-1-12	2		2		
	M-5-74	1		1		
	None	3		3		
M-6-19	B-1-12	1	1			
S-5009	B-1-12	3		3		
	M-6-19	3		3		
	None	2		2		
None	B-1-12	3	1	2		
	B-3-23	1		1		
	M-5-14	1		1		
	None	2				2

*Scion-stock union unsuccessful.

60°F, which temperature had previously been found suitable for symptom expression by P. mahaleb.

Summarily expressed, the results were that all but four of the previously inoculated trees developed symptoms, whether reinoculated or not. Of the 62 previously inoculated trees which showed unmistakable (moderate or severe) symptoms, 13 had not been reinoculated. Some of these had shown symptoms at 60°F after the first inoculation one year before. Of the seven living trees not previously inoculated, five were inoculated with virus and showed symptoms; two were not inoculated, had been shown by indexing to be free of virus, and did not show symptoms. Detailed results are recorded in Table 3.

It is evident that symptoms occurred on these P. mahaleb seedling trees, even for the second time, during the second period of growth after inoculation, and that these viruses were not latent in P. mahaleb.

Symptom Expression on P. tomentosa at Three Greenhouse Temperatures

During these experiments and others in which P. tomentosa has been used for greenhouse indexing of Prunus species for virus, it seemingly had been satisfactory at a variety of temperatures and at variable temperatures. However, to provide precise information, a series of P. tomentosa seedling trees were inoculated at bud break by inserting cherry buds containing known sources of virus and incubated in the greenhouse at 60°, 70°, or 80°F. There were seven sources of virus. Nine P. tomentosa trees were inoculated with each source; three of these were incubated at each temperature.

All trees were observed each day for symptom expression, with results as follows and as recorded in part in Table 4. P. tomentosa reacted to all seven sources of virus and symptom expression was definite at all three temperatures. Shortest average time to symptom expression was at 80°F (6 to 11 days), longest at 60°F (17 to 25 days) and intermediate at 70°F (12 to 16.7 days). It is of interest that on the basis of time to symptom development, the seven sources were in the same order at all three temperatures. In general, those sources inducing symptoms in the shortest time induced the most severe symptoms, but the types of

Table 4. Time to symptom expression by P. tomentosa after inoculation with virus and incubation at one of three temperatures.

Virus source	Days to symptom expression after incubation in greenhouse at: 60°F	70°F	80°F
B-3-22	17	12	6
Local	17	13	6
B-1-12	22	14	8
C-2-1	22	15	9
S-5009	23	16.3	10
M-6-19	25	16.7	11
M-5-74	25	16.7	11

symptoms were essentially the same for all sources, namely, chlorotic mottling with or without necrotic rings on the leaves of new growth, accompanied in the majority of cases by necrosis of growing points. Every P. tomentosa seedling exhibited definite symptoms.

It is evident that greenhouse temperatures within the range of 60°- 80° F, were satisfactory for necrotic ring spot symptom development on P. tomentosa.

SUMMARY AND CONCLUSIONS

The possibility of indexing P. mahaleb by an "indirect" method comparable to that of Moore and Keitt (4) for sour cherry was experimentally explored as follows: (a) 126 P. mahaleb seedling trees were inoculated with one of 14 sources of virus, nine trees per source. Three seedling trees per source, plus three uninoculated check trees, were incubated at each of three greenhouse temperatures, 60°, 70°, and 80° F (to test reliability of symptom expression by P. mahaleb at these temperatures), After being out of doors during the summer and fall, these same P. mahaleb trees were (b) indexed on P. tomentosa (to test for continued presense of virus) and (c) a portion -- three per each original inoculation virus source -- inoculated with a similar virus source, a similar portion inoculated with a dissimilar virus source and the remaining portion left without a second inoculation; all were incubated in a greenhouse held at 60° F. This latter procedure was to test for possible latency and cross protection.

Virus symptoms were reliably expressed on P. mahaleb at 60°, not at 70° or 80° F. Thirty-eight of the 42 inoculated trees showed definite symptoms at 60°, 4 of 42 at 70°, and none at 80°. The three uninoculated check trees at each temperature remained free of symptoms.

A year after inoculation, all but twelve of the inoculated P. mahaleb seedling trees indexed virus-positive on P. tomentosa, allowing for death of plants and failures of bud graft unions.

Also, a year after inoculation, during the second growth period after inoculation, all but four of the 74 previously inoculated trees which remained alive showed symptoms, with or without reinoculation. In fact, 13 showed very definite symptoms without reinoculation, some for the second time (those incubated at 60° F after inoculation the previous year).

Because P. mahaleb expressed only moderate symptoms at 60°, mild if at all at 70°, and none at 80° F, it probably would not express symptoms in the greenhouse sufficiently well to enable its use as an index plant. Furthermore, since it did express symptoms one year after inoculation, during the second growth period, P. mahaleb did not express virus latency, as is the case with sour cherry. Because of lack of latency, it was not possible to determine the cross-protection phenomenon in P. mahaleb, as it occurs also in cherry. There is no need to consider the "indirect" method of indexing P. mahaleb, even if symptom expression were entirely at a particular temperature, which apparently it is not.

The demonstrated suitability of P. tomentosa as an index plant for detection of virus in P. mahaleb offers a satisfactory alternative. Indexing on P. tomentosa in this experiment failed to detect virus in only 12 of 126 inoculated P. mahaleb seedling trees, despite rather poor bud graft unions in general. Furthermore, when inoculated with virus-infected cherry

buds, P. tomentosa exhibited definite symptoms at greenhouse temperatures of 60°, 70°, and 80°F, the more rapidly and distinctly at the higher temperatures. This response is comparable to that of sour cherry, P. pumila, P. virginiana, and P. besseyi (3) and is a desirable attribute of an index plant.

REFERENCES

1. Fink, H.C. Prunus tomentosa as an index plant for necrotic ring spot of sour cherry. (Abst.) Phytopath. 40:9. 1950.
2. Fridlund, P.R. The reaction of Prunus tomentosa seedlings to latent Prunus virus cultures. (Abst.) Phytopath. 44:488-489. 1954.
3. Moore, J.D. and G.W. Keitt. Relation of temperature to expression of symptoms of yellows and necrotic ring spot. (Abst.) Phytopath. 36:406-407. 1946.
4. _____, _____. An indexing method for necrotic ring spot and yellows of sour cherry. (Abst.) Phytopath. 39:15-16. 1949.

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EFFECTIVENESS OF TWO PHEASANT FLUSHING BARS UNDER IOWA CONDITIONS[1]

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One of the most important problems in the management of the ring-necked pheasant, Phasianus colchicus, in Iowa's primary pheasant range is the serious loss in production suffered during the nesting season. A major portion of this loss occurs when a large number of nesting hens are killed or injured during the mowing of the first crop of hay, which usually takes place when pheasant nesting is at its peak. The development and subsequent widespread use of high speed tractor mowers has been responsible for much of this decimation.

One method of reducing this yearly loss in production that has been tried with varying success is the use of game flushing bars. The early flushing bars were designed for use on horse drawn mowers and were usually of flimsy construction. Consequently, they could not be adapted for use with high speed tractor mowers. Warvel (1949) constructed and tested two types of tractor-mounted flushing bars in Ohio. From these experiments evolved the Ohio Game Flushing Bar, which is constructed entirely of metal and is quite substantial.

The Ohio Flushing Bar utilized weights suspended on cables to supply the flushing stimulus as they drag through the hay. It has been suggested (Kemptar, 1953) that excellent results might be obtained with a bar utilizing strips of 6 inch belting painted white. An attempt was made to determine the relative efficiencies of the two types of flushing bars during the mowing of the first crop of hay on the Winnebago Pheasant Research Area (Baskett, 1947) in north-central Iowa. The mowing took place from June 14 to June 20, 1954.

Field Techniques

Sixteen hayfields, totaling 126 acres and ranging from 2 to 22 acres in size, were selected for the study. Alfalfa was the primary cover type in

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ten of the fields, red clover in five, and sweet clover in one. The flushing bar with cables and weights was used on the first half of eight of the fields and on the last half of the remaining eight. The flushing bar with strips of white belting was used on the other half of each field. The selection of the half of the field in which each bar was used was by means of a restricted random sample.

The observer rode on the tractor during the mowing operation on all but about 20 acres, watching the flushing bar and mower at all times. Whenever a hen was flushed, the tractor was stopped and the tractor operator and observer made a search for a nest and any signs of injury to the hen. The fields were walked immediately after mowing was finished, if possible, and immediately after the hay was raked into windrows in all instances. On the 20 acres in which the observer was unable to be on the tractor during mowing (two farmers mowing at the same time), the tractor operator reported his observations, and the fields were then walked before and after raking in search of further sign.

As a further check on the efficiencies of the two bars, no bar of any kind was used on six fields, totaling 50 acres. The other techniques were essentially the same. Mowing of these fields took place from June 16 to July 15.

Effectiveness of Flushing Bars

The relative performance of the two bars during the tests is shown in Table 1. For purposes of statistical comparison, the hens killed and hens injured were considered as one group. Chi-square tests indicated a significant difference ($X^2 = 4.24$, .05 level = 3.84) between the results obtained with the cables and weights and those obtained with the belt strips, the former being more efficient. A significant difference ($X^2 = 8.61$, .01 level = 6.64) was found between the cables and weights and no bar. The difference between the strips of belting and no bar was not significant. However, there was no reason to believe that the belt strips did not save hens.

By transforming the performance of the two flushing bars into percentages, it was found that the cables and weights were 63 per cent more effective than the belt strips in saving pheasant hens from death or injury. The belt strips were 31 per cent more effective than no bar, and the cables and weights were 75 per cent better than no bar. The latter figure is somewhat higher than the 45 per cent reduction in mortality and crippling found by Warvel (1949) in Ohio and the 33 per cent decrease found by Robbins (1954) on the Winnebago Area in 1953. Bue and Ledin (1954), in limited tests in Minnesota, found that flushing bars reduced mortality roughly 60 per cent.

A comparison of the relative effectiveness of the bars in different densities of cover (Table 2) showed no difference between the two types in light or medium cover. However, the cables and weights did a better job of flushing hens in the heavier cover.

A definite preference for the earlier developing alfalfa and sweet clover was exhibited by the nesting hens (Table 3). The fields were classified by the major plant present, though most consisted of combinations such as alfalfa-timothy, sweet clover-red clover, red clover-timothy, etc.

Table 1. Results of study to determine relative effectiveness of two types of flushing bar, Winnebago Area, Iowa, 1954

	Cables and Weights		Belt Strips		No Bar	
	Number	Percentage	Number	Percentage	Number	Percentage
Hens killed	0	0.0	1	3.1	6	35.3
Hens injured	5	14.7	12	37.5	4	23.5
Hens not injured	29	85.3	19	59.4	7	41.2
Total	34	100.0	32	100.0	17	100.0

Table 2. Effectiveness of Two Types of Flushing Bars in Varying Densities of Cover, Winnebago Area, Iowa, 1954

Density of Cover	Cables & Weights			Belt Strips			No Bar			Total		
	Kill.	Inj.	Non-Inj.	Kill.	Inj.	Non-Inj.	Kill.	Inj.	Non-Inj.	Kill.	Inj.	Non-Inj.
Light[1]	0	0	1	0	0	1	0	0	2	0	0	4
Medium[2]	0	0	7	0	0	5	2	1	3	2	1	15
Heavy[3]	0	5	21	1	12	13	4	3	2	5	20	36

1 - Less than 50% of ground covered.
2 - From 50 - 90% of ground covered.
3 - From 90 - 100% of ground covered.

Table 3. Effectiveness of Two Types of Flushing Bars in Different Types of Cover, Winnebago Area, Iowa, 1954

Types of Cover	Cables & Weights			Belt Strips			Totals			Total Acres Mowed	Acres Per Hen Flushed
	Kill.	Inj.	Non-Inj.	Kill.	Inj.	Non-Inj.	Kill.	Inj.	Non-Inj.		
Alfalfa	0	2	18	0	8	12	0	10	30	52	1.3
Red Clover	0	1	3	0	1	5	0	2	8	56	5.6
Sweet Clover	0	2	8	1	3	2	1	5	10	18	1.1

There was little difference in the mortality and crippling of hens in alfalfa (25 per cent) and red clover (20 per cent). In sweet clover, the heaviest cover present, 37.5 per cent of the hens flushed were killed or injured. The two bars were about equally effective in red clover, but red clover stands on the area were poorer than usual in 1954. The advantage of the cables and weights over the belt strips in alfalfa and sweet clover was evident.

Hens that were on nests suffered heavier casualties than those which were not Table 4). There was little difference between the two bars when the hens were not on a nest, but the cables and weights were about twice as effective in flushing those hens that were on nests.

Table 4. Relative Effectiveness of Flushing Bars upon Hen Pheasant on Nests and not on Nests, Winnebago Area, Iowa, 1954

Fate of Hens	Cables & Weights		Belt Strips		No Bar		Totals	
	On Nest	Not on Nest	On Nest	Not on Nest	On Nest	Not on Nest	On Nest	Not on Nest
Killed	0	0	1	0	5	1	6	1
Injured	3	2	11	1	4	1	17	4
Non-injured	10	19	13	6	3	3	27	28
Percent Killed or Injured	23	10	48	14	67	40	46	15

No definite relationship was found between the number of hens killed and injured and the stage of incubation of their nests, except hens with nests still in the laying stage appeared to escape more readily (Table 4), The average incubation stage of nests found when the cables and weights were in use was 6.3 days; when the belts were in use, 7.1 days; and when no bar was in use, 8.9 days.

Time of Mowing

When a hen was flushed, the time of day was recorded. When a nest from which no hen had flushed was later found, the approximate time that the mower passed over the nest was computed. These results were summarized by hourly periods (Table 6). It would appear that the killing and injury of hens could be decreased if a larger portion of hay mowing was done during the 7-10 a.m. and 3-6 p.m. periods. Only 16 per cent of the hens flushed during these intervals were killed or injured, compared to 48 per cent of the hens flushed during the 10 a.m. to 2 p.m. period (Table 7). About 45 per cent of the mowing was done from 7-10 a.m. and 3-6 p.m. and about 40 per cent of the hens flushed; yet, only 21 per cent of the killing and injury occurred during this time. All but two of the 20 nests with the hen absent when the mower passed were found during

Table 5. Relationship between Number of Hens Killed (K), Injured (I), or Non-injured (N-I) and the Stage of Incubation of Their Nests, Winnebago Area, Iowa, 1954

Stage of Incubation in Days	Cables & Weights			Belt Strips			No Bar			Totals		
	K	I	N-I	K	I	N-I	K	I	N-I	K	I	N-I
0	-	-	3	-	-	6	-	-	1	-	-	10
1-3	-	-	-	1	-	3	1	-	1	2	-	4
4-6	-	2	3	-	2	-	1	1	-	1	5	3
7-9	-	1	1	-	1	1	2	1	-	2	3	2
10-12	-	-	1	-	5	1	-	-	-	-	5	2
13-15	-	-	2	-	2	1	-	-	2	-	2	5
16-18	-	-	-	-	-	1	1	-	-	1	-	1
19-23	-	-	-	-	1	-	-	1	-	-	2	-

Table 6. Relationship between Number of Hens Killed (K), Injured (I), or Non-injured (N-I) and Time of Flushing, Winnebago Area, Iowa, 1954

Time of Day	Cables & Wts.				Belt Strips				No Bar				Total				Nest-No Hen
	K	I	N-I	Ac.* Cut	K	I	N-I	Ac. Cut	K	I	N-I	Ac. Cut	K	I	N-I	Ac. Cut	
7-8 a.m.	-	-	4	2.7	-	-	-	0.0	-	-	-	0.0	-	-	4	2.7	3
8-9 a.m.	-	1	5	7.3	-	-	1	2.3	-	-	2	4.6	-	1	8	14.2	4
9-10a.m.	-	1	2	5.0	-	2	5	10.2	-	-	-	2.5	-	3	7	17.7	3
10-11a.m.	-	1	2	6.1	-	4	3	10.4	1	-	2	7.1	1	5	7	23.6	1
11-12a.m.	-	-	2	4.8	-	2	1	5.1	2	1	1	8.8	2	3	4	18.7	-
1-2 p.m.	-	1	4	11.1	-	1	1	5.3	1	2	1	10.7	1	4	6	27.1	-
2-3 p.m.	-	1	4	9.0	1	2	3	12.9	1	1	-	6.3	2	4	7	28.2	1
3-4 p.m.	-	-	4	7.6	-	1	3	9.1	-	-	-	2.2	-	1	7	18.9	4
4-5 p.m.	-	-	2	8.1	-	-	2	7.2	1	-	1	3.8	1	-	5	19.1	3
5-6 p.m.	-	-	-	1.3	-	-	-	0.5	-	-	-	4.0	-	-	-	5.8	1
Total	0	5	29	63.0	1	12	19	63.0	6	4	7	50.0	7	21	55	176.0	20

*Acres mowed during each hour

Table 7. Comparison of Pheasant Hen Mortality and Crippling During Early Forenoon + Late Afternoon Hours and Mid-Day Hours, Winnebago Area, Iowa, 1954

Type of Bar	No. Acres Mowed	No. Hens Flushed	Hens Flushed Per Acre	Hens Killed or Injured	Hens Not Injured	Acres Per Hen Killed or Injured
			7-10 a.m. + 3-6 p.m.			
Cables & Wts.	32.0	19	1.7	2	17	16.0
Belt Strips	29.3	14	2.1	3	11	9.8
No Bar	17.1	4*	4.3	1	3	17.1
Total	78.4	37	2.1	6	31	13.1
			10 a.m. - 3 p.m.			
Cables & Wts.	31.0	15	2.1	3	12	10.0
Belt Strips	33.7	18	1.9	10	8	3.4
No Bar	32.9	13	2.5	9	4	3.7
Total	97.6	46	2.1	22	24	4.4

*Sample size probably too small to show definite results

the 7-10 and 3-6 intervals. Of the 33 hens not on a nest when flushed, 21, or 64 per cent, were flushed during these two periods. Concurrent studies conducted on the same area indicated that laying or incubating hens were more likely to be off their nest during early forenoon and late afternoon than during the middle of the day.

DISCUSSION

On the basis of evidence gathered, it was apparent that the cables and weights were more effective in flushing pheasant hens than the belt strips under northern Iowa conditions in 1954. The belt strips did not have sufficient weight to penetrate the heavier cover. Some of the hens injured when the belts were being used had both legs severed and no other visible injury. Apparently the belts passing above them startled the hens enough to make them stand up but not enough to make them fly immediately. Since the hen has only about two seconds from the time the flushing bar passes over her until the mower bar arrives, she must be disturbed enough to make her flush at once. The heavier cables and weights were better able to penetrate the hay sufficiently to make contact, or near-contact, with many of the hens, causing them to flush without delay.

The necessity of painting the belts white was questionable. It was found that in dragging through the hay the belt strips soon became stained, especially in the early forenoon and late afternoon when the cover was damp. Since the hay in most of the fields was nearly tall enough to reach the top of the flushing bar, most of the belt strip was dragging in the heavy cover. Under such circumstances, it would be doubtful whether the hens could see a white belt any better than an unpainted darker one. No definite conclusions could be drawn, however, since all belts used were painted white and there was no quantitative basis for comparing them with nonwhite belts.

While the investigator was riding on the tractors during the study, it was found that 34 of 55 hens (62 per cent) flushed without injury were not seen by the tractor operator. It can be assumed that nearly all nests would be found whether riding on the tractor during mowing, and later walking the field, or only following the mower on foot. However, interpretation of nests where no hen flushed directly, or where a flushed hen was not injured, would be more difficult with the latter method. Nearly all instances of death or severe injury to the hen would be detected by either method. It should not be assumed that the tractor operators fail to see 62 per cent of the hens flushed when no observer is on the tractor with them. The presence of an observer undoubtedly influenced the degree of attention the tractor operator directed toward his mower. Any malfunctioning or clogging of the mower would be brought to the operator's attention by the observer. Thus, it would be unnecessary for the tractor operator to be constantly glancing rearward. It was apparent, however, that the method of determining the number of injured and uninjured hens would affect the percentage results obtained.

Several suggestions and ideas for improving the flushing bars were entertained, many coming from the cooperating farmers and other interested parties. The most common suggestion was to place the cables and weights closer than the 10 inches in the original plans. Further work would be necessary to determine how close the cables could be without tangling resulting. It was the opinion of the tractor operators that the added weight of a few more cables and weights would have no effect on the handling of the tractor. Another frequently mentioned idea was to insert a belt strip between each cable, thus combining the two bars in effect.

SUMMARY

1. Two types of flushing bars, one employing weights suspended on cables and the other heavy strips of belting to provide the flushing stimulus, were tested for relative effectiveness.

2. The tests were conducted during the mowing of the first crop of hay on the Winnebago Pheasant Research Area in north-central Iowa in 1954.

3. A significant difference was found between the results obtained with the cables and weights and those obtained with the belt strips, the former being more efficient.

4. There was no difference between the effectiveness of the two bars in light or medium cover, but a pronounced advantage in favor of the cables and weights in heavy cover.

5. Hens that were on a nest when flushed suffered a higher rate of mortality and crippling than hens not on a nest. No definite relationship was found between the rate of killing and injury of hens and the stage of incubation of their nests.

6. A higher percentage of hens were killed or injured from 10 a.m. to 3 p.m. than from the combined 7 to 10 a.m. and 3 to 6 p.m. periods. Most of the hens not on a nest when flushed and nests with the hen absent were found during the last two periods.

7. A better flushing bar might result if the cables and weights were placed closer together. Another possibility was placing a belt strip between each cable, thus combining the two bars in effect.

REFERENCES

Baskett, T.S. Nesting and production of the ring-necked pheasant in north-central Iowa. Ecol. Monogr. 17(1):1-30. 1947.

Bue, Gerald T. and Donald H. Ledin. Flushing bars improve hunting. Minnesota Conservation Volunteer 17(98):34-49. 1954.

Kemptar, B. Flushing bar reduces loss of hens, young. Outdoor Nebraska 31(3):17, 23. 1953.

Robbins, R.L. Efficiency of the Ohio game flushing bar under Iowa conditions. Unpubl. M.S. thesis. Iowa State College. 1954.

Warvel, H. The development of an upland game flushing bar. Unpubl. M.S. thesis. Ohio State University. 1949.

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COMPARATIVE PATHOGENICITY OF PYTHIACEOUS FUNGI ON CORN[1]

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It has been well established that Pythium debaryanum Hesse causes pre-emergence and post-emergence damping off and root necrosis in many speeies of grasses and broad-leafed plants. Pythium graminicolum Subr. is quite commonly parasitic on the roots of grasses, small grains and corn beyond the seedling stage. Recent studies (9, 10) have shown, however, that the majority of unidentified pythiaceous fungi isolated from straw taken from field soil produced oospores only in specific culture matings. Results obtained by Staffeldt (11) indicated that cultures of these isolates were markedly less pathogenic on corn seedlings than P. graminicolum, which was not isolated from straw.

In view of the predominance of such unidentified Pythium forms in field soil, trials of pathogenicity were conducted in which four such isolates, taken from necrotic corn roots and designated 87A, 87B, 98A, and 98B, were tested separately and in all possible mating combinations and compared with known cultures of P. debaryanum and P. graminicolum. Fungus cultures were evaluated on three strains of corn at two moisture levels over five sets of temperatures.

Pertinent Literature

Johann, Hobart, and Dickson (7) presented data to show that pre-emergence damping off was enhanced by low temperatures and high levels of soil moisture, and Flor (5) demonstrated that injury to germinating corn and corn seedlings was greatest at moisture levels above 50 per cent of soil water holding capacity and at temperatures below 20° C. Temperature was considered by Dickson (3) to be the most important single factor determining the extent of infection of corn and wheat seedlings by Gibberella zeae Schw.

Leach (8) found that the incidence of pre-emergence damping off was inversely proportional to the rate of growth of the host plants. This finding, which involved a specific relationship among pathogen, suscept, and environment, was supported in work with other fungus species by Buchholtz (1), Carpenter (2), Edgerton, Tims, and Mills (4) and Vanterpool and Truscott (14).

Trost (13), Hooker and Dickson (6), and Stutzman (12) have indicated that inbred lines and hybrid strains of corn differ markedly in their resistance to corn root pathogens under adverse planting conditions.

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Materials and Methods

Pythium graminicolum and unidentified Pythium isolates designated as 87A, 87B, 98A, and 98B were obtained from necrotic roots of field-grown corn. Pythium debaryanum was isolated from a corn kernel which had been infected and killed in infested peat soil before germination. Cultures tested included P. graminicolum, P. debaryanum, 87A, 87B, 87A + 87B, 98A, 98B, 98A + 98B, 98A + 87B, and 87A + 98B. The fungus isolates were evaluated on resistant and susceptible experimental hybrids, X5171 and X9180 respectively, and a susceptible inbred line, WF9.

Inoculum was prepared by mixing sterile quartz sand with agar cultures of fungus isolates. A 1/2-inch layer of inoculum was applied over peat soil in 4-inch pots. Corn kernels were planted in the layer of inoculum and covered with sterile sand.

Two moisture levels, 60 per cent and 20 per cent of water holding capacity, were employed. Moisture levels were maintained from time of planting until the plants were washed and examined.

A preliminary survey was conducted to determine temperature conditions which would allow the expression of extreme pathogenicity as well as those which would allow expression of maximum differences among the fungus cultures. On the basis of this survey the following five sequences of temperatures were selected:

I. Incubation at 25°C continuously.
II. Five-day incubation at 16°C, followed by transfer to 25°C.
III. Ten-day incubation at 16°C, followed by transfer to 25°C.
IV. Five-day incubation at 10°C, followed by transfer to 25°C.
V. Ten-day incubation at 10°C, followed by transfer to 25°C.

Diseased seedlings were allowed to grow to the three-leaf stage and were then washed and examined. These seedlings, and kernels which had been infected and killed before germination, were evaluated and assigned disease ratings which were scaled numerically one to six according to severity of infection. A total of such numbers for 20 plants within each pot was derived. Such totals were converted to disease indices and the average of index values over four pots, i.e., replications, constituted culture means at each level of host resistance and moisture. Graphical presentation of relative culture behavior was adapted from means of culture indices over all conditions within each sequence of temperatures.

A completely randomized experimental design was used. The error sum of squares was composed of the residual sum of squares plus the sum of squares of replicates and replicate interactions.

Experimental Results

Analysis of variance of the data presented in Table 1 shows that variations attributable to fungus cultures, strains of corn, moisture levels, temperature sequences, and all interactions of these factors were significant at the 1 per cent level of testing.

Examination of culture indices showed that the relative pathogenicity between Pythium graminicolum and P. debaryanum and cultures of isolates 87A, 87B, 98A, and 98B varied markedly both within and between sequences of temperatures. Within-temperature-sequence averages of

Table 1. Summary of Analysis of variance of Data from All Temperature Sequences

Source of variation[a]	DF	MS	F
C	10	21,483.3	257.36[b]
M	1	6,162.0	1,166.74[b]
S	2	142,378.5	1,709.22[b]
TS	4	91,190.2	73.97[b]
C x S	20	953.0	11.44[b]
C x TS	40	231.6	2.78[b]
C x M	10	498.1	5.98[b]
S x TS	8	5,664.6	68.00[b]
S x M	2	1,688.0	20.26[b]
TS x M	4	4,919.5	59.05[b]
C x S x TS	80	439.3	5.27[b]
C x M x S	20	220.6	2.64[b]
S x TS x M	8	935.0	11.22[b]
C x M x TS	40	368.6	4.42[b]
C x M x S x TS	80	168.7	2.02[b]
Error	990	83.3	
Total	1319		

[a] C = Cultures; M = Moistures; S = Strains; TS = Temperature Sequences.

[b] Significant at the 1 per cent level.

disease indices for cultures presented graphically in Fig. 1 show that neither a single isolate nor a group of isolates were consistently most pathogenic. P. graminicolum and P. debaryanum, used specifically as comparison standards, were notably most pathogenic in temperature sequence I. However, this margin was not maintained in temperature sequence II and III. All cultures of isolates 87A, 87B, 98A, and 98B were more pathogenic than P. graminicolum and P. debaryanum in temperature sequence V. High daytime greenhouse temperatures in temperature sequence IV resulted in low levels of disease and nonsignificant margins among culture indices.

Fungus cultures, in which matings among A and B components of isolates 87 and 98 had been made, contained an abundance of oospores at the time they were used as inoculum. However, combinations of mating components resulting in the production of these sexual spores did not observably affect pathogenicity under any of the test conditions.

Mature corn plants were inoculated with isolate 87A which had been cultured on steamed barley. An identical pattern of resistance and susceptibility among lines of corn was shown on mature plants as was shown in greenhouse studies with seedlings.

Summary and Conclusions

Pronounced differences in relative pathogenicity among fungus cultures were apparent in numerous instances under specific conditions of moisture and host resistance within temperature sequences. However, the

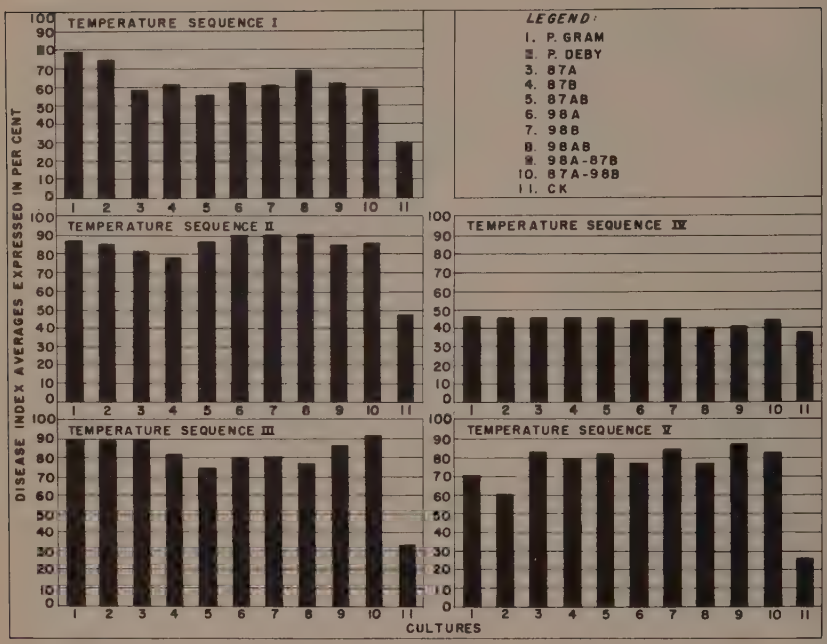

Fig. 1. The comparative pathogenicity of Pythium cultures shown as disease index averages over two levels of moisture and three lines of corn within sequences of temperatures

rank in pathogenicity among cultures was highly variable both within and among sequences of temperatures.

Cultures of isolates 87A, 87B, 98A, and 98B were either equally pathogenic to or more pathogenic than cultures of Pythium graminicolum or P. debaryanym under numerous conditions of specific levels of host resistance and moisture. All cultures of these isolates were more pathogenic than either P. graminicolum or P. debaryanum under most conditions provided in temperature sequence V. Thus, isolates 87A, 87B, 98A, and 98B seem potentially as important as pathogens of corn roots as do the well known "standards", P. graminicolum and P. debaryanum.

Cultures resulting from matings amond A and B components of isolates 87 and 98 were neither more nor less pathogenic than cultures of unmated components.

Inoculation of mature plants with isolate 87A gave identical reactions among lines of corn to those obtained in greenhouse experimentation with corn seedlings.

REFERENCES

1. Buchholtz, W.F. Factors influencing the pathogenicity of Pythium debaryanum on sugar beet seedlings. Phytopath. 28:448-475. 1938.
2. Carpenter, C.W. Notes on Pythium root rot. Hawaii Planter's Record 34:84-98. 1930.
3. Dickson, J.C. Influence of soil temperature and moisture on the development of seedling blight of wheat and corn caused by Gibberella saubinetti. Jour. Agr. Res. 23:837-870. 1923.
4. Edgerton, C.W., E.C. Tims, and C.J. Mills. Relation of species of Pythium to the root rot disease of sugar cane. Phytopath. 19: 549-564. 1929.
5. Flor, H.H. Relation of environmental factors to growth and pathogenicity of Pythium isolated from roots of sugar cane. Phytopath. 20:319-328. 1930.
6. Hooker, A.L. and J.G. Dickson. Resistance to Pythium manifest by excised corn embryos at low temperatures. Agron. Jour. 44:443-447. 1952.
7. Johann, Helen, J.R. Holbert, and J.G. Dickson. A Pythium seedling blight and root rot of dent corn. Jour. Agr. Res. 37:443-464. 1928.
8. Leach, L.D. Growth rates of host and pathogen as factors determining the severity of preemergence damping-off. Jour. Agr. Res. 75:161-179. 1947.
9. Semeniuk, G. Pythium colonization of plant debris. Iowa Agr. Exp. Sta. Rpt. 373-374. 1948.
10. Staffeldt, E.E. Pythium and other fungi colonizing sterilized straw in the soil. Unpubl. M.S. thesis, Iowa State College Library, 1951.
11. _____. Effects of four crop rotations on soil fungi and corn necrosis. Unpubl. Ph.D. thesis, Iowa State College Library. 1953.
12. Stutzman, Roy. The response of inbred lines and single crosses of Zea mays L. to Pythium graminicolum Subr. Unpubl. M.S. thesis, Iowa State College Library. 1942.
13. Trost, J.F. Relation of the character of the endosperm to the susceptibility of dent corn to root rotting. USDA Bull. No. 1062, 1-7. 1922.
14. Vanterpool, T.C. and J.H.L. Truscott. Studies of the browning root rot of cereals II. Some parasitic species of Pythium and their relation to the disease. Canad. Jour. of Res. 6:68-93. 1932.

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THE THEORY OF VIBRATING JETS IN LIQUIDS OF VARIABLE SURFACE TENSIONS*

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ABSTRACT

The theory of jet oscillations in a liquid of time dependent surface tension has been analyzed. To the extent that the surface tension change can be represented as linear over a single wave length, the wave length is approximately that given by the non-time dependent equations with surface tension constant at the mean value over the wave length. A high frequency low-amplitude oscillation will be superimposed on the principal jet motion, which should, however, present negligible complications under usual experimental conditions.

The theory of vibrations of liquid jets issuing from noncircular orifices has been developed by Rayleigh (1), Pedersen (2), and Bohr (3) for the case of liquids of constant surface tension. The basic treatment assumes the liquid nonviscous, wave amplitudes very small, and neglects damping of the vibrations by air or other media into which the jet issues; first order corrections for these effects have been developed by Bohr.

In systems containing more than one component, adsorption at the liquid surface may be generally expected, and may further be expected to occur at a finite rate. The possibility of measuring this rate by surface tension measurements over short time intervals immediately after surface formation using the vibrating jet technique has attracted experimental investigations by a number of workers, especially Addison (4). So far as the present author is aware, no modification of the vibrating jet theory to adapt this theory to variable surface tensions has been published. Previous investigators have computed surface tensions from measured wave lengths using equations developed for the constant surface tension case. That this is somewhat rash may be seen most readily

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(1) Lord Rayleigh. Proc. Roy. Soc. 29:71-97. 1879.
(2) Pedersen, P.O. Phil. Trans. A207:341. 1907.
(3) Bohr, N. Phil. Trans. A209:281. 1909.
(4) Addison, C.C. J. Chem. Soc. 1943:535. 1943.
J. Chem. Soc. 1944:252,477. 1944.
J. Chem. Soc. 1945:98,354. 1945.
J. Chem. Soc. 1946:579. 1946.

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from a consideration of the rather analogous problem of a linear harmonic oscillator with time dependent force constant; the general problem in this case has not been solved, and in particular the motion is not properly represented by a function of the type $\cos\left(\sqrt{\frac{k}{m}}\,t + \epsilon\right)$, where m is the oscillator mass and k the (time dependent) force constant.

The purpose of this paper is to present a first order solution to the variable surface tension vibrating jet problem and to indicate experimental conditions under which this first order treatment should be adequate for interpretation of experimental results. A more general solution would be desirable but does not appear easily obtainable. The first order corrections of Bohr may be taken over in the present theory; accordingly this treatment will be developed for an incompressible, nonviscous fluid, damping by air will be neglected, gravitational effects will be neglected, and the amplitudes of the waves will be considered small.

Consider a jet of liquid of initial surface tension T_o and density ρ flowing in the positive z direction from an orifice whose equation is

$$R(\theta,0) = a + b\cos n\theta \tag{1}$$

at a volume flow rate V cc/sec. We seek an equation for the surface of the jet of the form

$$R(\theta,z) = a + \alpha(z) + f(z)\cos n\theta \tag{2}$$

in which $(0) = 0$, $f(0) = b$. We shall assume that α and f are small compared to a. With the assumptions made as to the character of liquid and flow, the velocity is derivable from a velocity potential $\phi(r,\theta,z)$ such that $\vec{v} = -\operatorname{grad}\phi$ and the jet system must satisfy the equations

$$\nabla^2\phi = 0 \tag{3}$$

$$\phi(r,\theta + 2m\pi,z) = \phi(r,\theta,z) \tag{3a}$$

$$-\left(\frac{\partial\phi}{\partial r}\right)_{z=0} = 0 \tag{3b}$$

$$\frac{v_R}{v_z} = \frac{dR}{dz} \tag{4}$$

$$T\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + \frac{1}{2}\rho v^2 = \text{constant} \tag{5}$$

Eq. (3) requires the velocity potential to satisfy LaPlace's equation: the boundary conditions (3a, 3b) require respectively that the velocity potential be single-valued and that the velocity have no radial component at the orifice. Eq. (4), in which v_R is the radial component of the velocity and v_z, the axial component at the jet surface, requires that the direction of flow at the surface be parallel to the surface, and hence that the jet configuration be time independent. Eq. (5) requires variations in pressure due to velocity variations to be compensated by pressure changes resulting from surface tension and altered principal curvatures.

We assume the jet to be cylindrical in zeroth order, and seek the first order deviations from cylindrical form. The principal part of the velocity will then be a z component of $v_o = V/\pi a^2$, and there will be correspondingly a leading term $-v_o z$ in the velocity potential, compared to which other terms will be small in first order.

The most general solution of the boundary value problem (3, 3a, 3b) retaining orifice symmetry is

$$\phi(r,\theta,z) = -v_o z + \int_0^\infty \sin kz\,[A(k)J_o(ikr) + B(k)J_n(ikr)\cos n\theta]\,dk \tag{6}$$

in which A(k) and B(k) are arbitrary functions to be determined subsequently and $J_o(ikr)$ and $J_n(ikr)$ are Bessel's functions of orders and arguments indicated.

From Eq. (4), using Eqs. (2) and (6) and setting $v_z = v_o$ since the term v_R/v_z is already small in first order

$$-\frac{1}{v_o}\int_0^\infty ik \sin kz\,[A(k)J_o'(ikR) + B(k)J_n'(ikR)\cos n\theta]\,dk$$

$$= \alpha'(z) + f'(z)\cos n\theta \tag{7}$$

whence, equating coefficients of cos nθ, setting R = a in first order terms and integrating

$$\alpha(z) = +\frac{1}{v_o}\int_0^\infty A(k)J_o'(ika)\cos kz\,dk \tag{8}$$

$$f(z) = +\frac{1}{v_o}\int_0^\infty B(k)J_n'(ika)\cos kz\,dk\,. \tag{9}$$

At the surface of the jet, again setting R = a in first order terms

$$v_z = \frac{\partial\phi}{\partial z} = v_o - \int_0^\infty k\cos kz\,[A(k)J_o(ika) + B(k)J_n(ika)\cos n\theta]\,dk \tag{10}$$

The second term in (10) is small in first order; the velocity components normal to the jet axis will contain only first order terms. Hence, in evaluating v^2 only the v_z component will lead to a first order term, and we have correct to first order

$$v^2 = v_o^2 - 2v_o \int_o^\infty k \cos kz\left[A(k)J_o(ika) + B(k)J_n(ika) \cos n\theta\right]dk. \tag{11}$$

The sum of the principal curvatures is, to first order*

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R} - \frac{1}{R^2}\frac{\partial^2 R}{\partial \theta^2} - \frac{\partial^2 R}{\partial z^2} \tag{12}$$

$$= \frac{1}{a} - \frac{R-a}{a^2} - \frac{1}{a^2}\frac{\partial^2 R}{\partial \theta^2} - \frac{\partial^2 R}{\partial z^2}. \tag{13}$$

Using Eq. (2)

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{a} - \frac{\alpha(z)}{a^2} - \alpha''(z) - \cos n\theta\left[f''(z) - \frac{n^2-1}{a^2}f(z)\right] \tag{14}$$

and hence by application of Eqs. (8) and (9)

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{a} + \frac{i}{v_o}\int_o^\infty \cos kz\left[A(k)J_o'(ika)\left(k^2 - \frac{1}{a^2}\right)\right.$$

$$\left. + B(k)J_n'(ika)\left(k^2 + \frac{n^2-1}{a^2}\right)\cos n\theta\right]dk \tag{15}$$

Applying the results expressed in Eqs. (11) and (15) to Eq. (5) we obtain

$$\frac{T}{a} + \frac{1}{2}\rho v_o^2 + \int_o^\infty \cos kz \quad A(k)\left[\frac{iT}{v_o}J_o'(ika)\left(k^2 - \frac{1}{a^2}\right) - \rho v_o k J_o(ika)\right]$$

$$+ B(k) \cos n\theta\left[\frac{iT}{v_o}J_n'(ika)\left(k^2 + \frac{n^2-1}{a^2}\right) - \rho v_o k J_n(ika)\right]dk$$

$$= \text{constant} \quad = \frac{T}{a} + \frac{1}{2}\rho v_o^2 \tag{16}$$

whence, considering coefficients of cos nθ it is necessary that

$$\frac{T}{a} + \frac{1}{2}\rho v_o^2 + \int_o^\infty \cos kz\, A(k)\left[\frac{iT}{v_o}J_o'(ika)\left(k^2 - \frac{1}{a^2}\right)\right.$$

$$\left. - \rho v_o k J_o(ika)\right]dk = \text{constant} \tag{17}$$

*This can be obtained by methods discussed in Forsyth 'Differential Geometry' pp. 37-44 assuming all derivative products small in higher order.

and

$$\int_0^\infty \cos kz\, B(k) \left[\frac{iT}{v_o} J_n'(ika)\left(k^2+\frac{n^2-1}{a^2}\right) - \rho v_o k J_n(ika) \right] dk = 0 \tag{18}$$

Now if T is constant, $\frac{T}{a} + \frac{1}{2} v_o^2$ in Eq. (17) is constant, the integral in Eq. (17) has therefore a constant value; no contradictions arise if this is taken as zero and the function A(k) taken as identically zero. If T is constant, we have by Fourier inversion of Eq. (18)

$$B(k) \left[\frac{iT}{v_o} J_n'(ika)\left(k^2+\frac{n^2-1}{a^2}\right) - \rho v_o k J_n(ika) \right] = 0 \tag{19}$$

so that B(k) can have non-zero values only at the roots of the bracketed quantity. If k_o denote the lowest root, the equation of the jet surface for the constant surface tension case is

$$R(\theta,z) = a + b \cos k_o z \cos n\theta \tag{20}$$

and from measured values of k_o the surface tension may be calculated from the equation

$$T = \frac{\rho v_o^2 k_o J_n(ik_o a)}{iJ_n'(ik_o a)\left[k_o^2 + \frac{n^2-1}{a^2}\right]} \tag{21}$$

If the surface tension is time dependent (hence, z dependent in the present problem) the integral in Eq. (17) cannot be assumed zero, and neither this integral nor the integral in Eq. (18) can be treated by Fourier inversion in the general case. For particular choices of the function T(z) some progress may be obtained by Fourier inversion; a rather simple and physically possible choice is

$$T - T_\infty = (T_o - T_\infty) e^{-cz} \tag{22}$$

in which T_o, T_∞, and C are constants. Using this expression for T the following integral equations are obtained by Fourier inversion of EQs. (17) and (18).

$$A(k)\left[\rho v_0 k J_0(ika) - \frac{iT_\infty}{v_0} J_0'(ika)\left(k^2 - \frac{1}{a^2}\right)\right] = -\frac{(T_0 - T_\infty)}{a}\left\{\delta(k) + \frac{2c}{\pi(c^2+k^2)}\right\} + \frac{i(T_0-T_\infty)c}{\pi v_0}\int_0^\infty A(k') J_0'(ik'a)\left(k'^2 - \frac{1}{a^2}\right)\left(\frac{1}{c^2+(k'+k)^2} + \frac{1}{c^2+(k'-k)^2}\right) dk' \qquad (23a)^*$$

$$B(k)\left[\rho v_0 k J_n(ika) \frac{iT_\infty}{v_0} J_n'(ika)\left(k^2 + \frac{n^2-1}{a^2}\right)\right] = \frac{i(T_0-T_\infty)c}{\pi v_0}\int_0^\infty B(k') J_n'(ik'a)\left(k'^2 + \frac{n^2-1}{a^2}\right)\left(\frac{1}{c^2+(k'+k)^2} + \frac{1}{c^2+(k'-k)^2}\right) dk' \qquad (23b)$$

These integral equations permit, in principle, solution for the functions A(k) and B(k), whence the functions $\alpha(z)$ and f(z) can be obtained in principle from Eqs. (8) and (9). In practice the integral equations (23a) and (23b) are intractable; even if solved it is by no means certain that the resulting integrals in Eqs. (8) and (9) could be evaluated analytically.

An approximate solution of the integral equation (18) may be obtained by converting it to an approximately equivalent differential equation solvable by successive approximation. This conversion is based on the presumption that the function B(k) has an appreciable value only for small values of (ka), so that terms in the integrand can be expanded in power series in (ka) and higher terms neglected. This presumption is physically well-justified, for B(k) can have important values only for small values of the bracketed portion of the integrand, and these occur at small values of ka.

Differentiation of Eq. (9) twice with respect to z leads to an analogous integral but with the integrand multiplied by $(-k^2)$, and the process can be iterated. Using the expansion

$$\frac{J_n(x)}{xJ_n'(x)} = \frac{1}{n}\left[1 + \frac{x^2}{2n(n+1)} + \cdots\right] \qquad (24)$$

*$\delta(k)$ is the Dirac δ function, i.e. $\lim_{k\to 0} \delta(k) = \infty$, $\delta(k) = 0$ for $k \neq 0$, and $\int_{-\infty}^{\infty} \delta(k)\, dk = 1$

and neglecting higher terms Eq. (18) is reduced to

$$\left(\frac{\rho v_o^2 a}{n} - T\right)f'' + \frac{T(n^2-1)}{a^2} f + \frac{\rho v_o^2 a^3}{2n^2(n+1)} f'''' = 0 \qquad (25)$$

Setting $T = \gamma_o + \gamma_1 X$ (valid for small z), assuming that $T/\rho v_o^2 a$ is small in first order compared to unity, and for successive approximation treatment setting $f = f_o + f_1$ where f_1 is small in first order compared to f_o, the differential equation (25) is reduced to the two equations

$$f_o'' + \frac{n(n^2-1)\gamma_o}{\rho v_o^2 a^3} f_o = 0 \qquad (26a)$$

$$f_1'' + \frac{n(n^2-1)\gamma_o}{\rho v_o^2 a^3} f_1 = \frac{n\gamma_o}{\rho v_o^2 a} f_o'' - \frac{n(n^2-1)\gamma_{1z}}{\rho v_o^2 a^3} f_o - \frac{a^2}{2n(n+1)} f_o'''' \qquad (26b)$$

of which the solution, subject to boundary conditions $f(o) = b$, $f'(o) = 0$ is

$$f(z) = b\left[\left(1 - \frac{\gamma_1 z}{4\gamma_o}\right)\cos k_o z - \left\{\frac{(3n-1)\gamma_o k_o z}{4\rho v_o^2 a} + \frac{\gamma_1 k_o z^2}{4\gamma_o} - \frac{1}{4k_o\gamma_o}\right\}\sin k_o z\right] \qquad (27)$$

in which $k_o^2 = \dfrac{n(n^2-1)\gamma_o}{\rho v_o^2 a^3}$

The integral equation (17) does not appear suited for a similar analysis. The lower root of the bracketed quantity in the integrand is imaginary, corresponding to an instable motion of the jet; the higher root corresponds to a value of ka large compared to unity. An expansion similar to that used in treatment of Eq. (18) is therefore not valid. The following treatment of the angularly independent motion therefore returns to the physical formulation of the problem, in which for this portion of the problem we may consider the orifice circular. Let T_o, a, v_o be the initial surface tension, jet radius, and velocity, and T, R, and v be the corresponding quantities at z. Conservation of energy and mass will then require

$$\frac{T}{R} + \frac{1}{2}\rho v^2 = \frac{T_o}{a} + \frac{1}{2}\rho v_o^2 \qquad (28)$$

$$\pi R^2 v = \pi a^2 v_o \tag{29}$$

Setting $R = a + \delta(z)$, $\delta(z)$ small in first order compared to a, there results

$$-\frac{\delta}{a} = \frac{T_o - T}{2\rho v_o^2 a + T} \approx \frac{T_o - T}{2\rho v_o^2 a} \tag{30}$$

$$v = v_o\left(1 - \frac{2\delta}{a}\right) \approx v_o\left(1 + \frac{T_o - T}{\rho v_o^2 a}\right) \tag{31}$$

Now let $T - T_o = \gamma_1 z$, valid for small z, A velocity potential consistent with Eqs. (3) and (4) can be constructed as follows:

$$v_R = v_z \delta'(z) \approx -\frac{\gamma_1}{2\rho v_o a} = -\left(\frac{\partial \phi}{\partial r}\right)_R \approx -\left(\frac{\partial \phi}{\partial r}\right)_a \tag{32}$$

whence if we select

$$-\phi = v_o z + \frac{\gamma_1 z^2}{2\rho v_o a} - \frac{\gamma_1 r^2}{4\rho v_o a} \tag{33}$$

it is evident that ϕ satisfies Eq. (3) and yields v_z and V_R correctly on differentiation. The function $\delta(z)$ does not, however, satisfy the boundary condition $\alpha'(o) = 0$. A complete first order solution is readily seen to be

$$\frac{\alpha(z)}{a} = + \frac{\gamma_1 z}{2\rho v_o^2 a}\left[1 - \frac{\sin k'z}{k'z}\right] \tag{34}$$

in which k' is the higher root, corresponding to stable motion, of

$$\frac{1T_o}{v_o}\left(k^2 - \frac{1}{a^2}\right)J_o'(1ka) - \rho v_o k J_o(1ka) = 0 \tag{35}$$

Using an asymptotic expansion for high ka this root is approximately given by

$$k' = \frac{\rho v_o^2}{T} \tag{36}$$

so that $k'a \gg 1$. The harmonic term in (34) will therefore be negligible in practice, the high frequency oscillatory motion will tend to be averaged over in practical measurement, and the boundary condition $R'(o) = 0$ can be replaced by $R'(o) = +\frac{\gamma_1}{2\rho v_o^2}$ (or alternately, the orifice position will not appear to be an extremum of the jet).

In near neighborhood of each value of z at which $f'(z) = 0$ there will be, by virtue of the magnitude of k', a value of z at which $\alpha'(z) = 0$. To sufficient approximation we can therefore consider the original boundary value problem iterated, presuming δ small sompared to f, at each root of

$$\delta'(z) + f'(z) = 0 \tag{37}$$

except that v_o should be replaced by $v_o(1 + \frac{T_o - T}{v_o^2 a})$ and a should be replaced by a $(1 - \frac{(T_o - T}{2\ v_o^2 a})$. Under usual experimental conditions these corrections will be negligible.

The roots of (37) in the neighborhoods of $\frac{2m\pi}{k_o}$ are obtained by substituting $-\gamma_1 z$ for $T_o - T$ in Eq. (30), and using first order expansions for sine and cosine functions in Eq. (27) in the neighborhood of $z = \frac{2m\pi}{k_o}$ to obtain

$$+\frac{\gamma_1}{2\rho v_o^2} - bk_o\left[(k_o z_m - 2m\pi) + \frac{(3n-1)\gamma_o \pi m}{2\rho v_o^2 a} + \frac{\gamma_1 \pi^2 m^2}{k_o \gamma_o}\right] = 0 \tag{38}$$

whence

$$k_o z_m = 2m\pi - \frac{(3n-1)\gamma_o \pi m}{2\rho v_o^2 a} - \frac{\gamma_1 \pi^2 m^2}{k_o \gamma_o} + \frac{\gamma_1}{2bk_o \rho v_o^2} \tag{39}$$

If the difference $z_{m+1} - z_m$ be denoted by λ_m, then considering z_o to be $+\frac{\gamma_1}{2bk_o^2 \rho v_o^2}$ rather than zero there results

$$\lambda_m = \frac{2\pi}{k_o} - \frac{(3n-1)\gamma_o \pi}{2\rho v_o^2 k_o a} - \frac{(2m+1)\gamma_1 \pi^2}{k_o^2 \gamma_o} \tag{40}$$

Now $k_o^2 = \frac{n(n^2-1)\gamma_o}{\rho v_o^2 a^3}$, and corresponds to the surface tension at the orifice. The surface tension midway between the mth and (m+1)st crest should be $\gamma_o + \frac{(2m+1)\pi\gamma_1}{k_o}$. If we define

$$K_m = \left[\frac{n(n^2-1)\gamma_o}{\rho v_o^2 a^3}\left(1 + \frac{(2m+1)\pi\gamma_1}{k_o \gamma_o}\right)\right]^{1/2}$$

$$= k_o\left[1 + \frac{(2m+1)\pi\gamma_1}{\gamma_o k_o}\right]^{1/2}$$

substitute in the first order term of (40) and expand we find

$$\lambda_m = \frac{2\pi}{k_m} - \frac{(3n-1)\gamma_o \pi}{2\rho v_o^2 k_o a} \tag{41}$$

$$= \frac{2\pi}{k_m} - \frac{(3n-1)k_o \pi a^2}{2n(n^2-1)} \tag{42}$$

Setting $k_o \approx k_m \approx \frac{2\pi}{\lambda_m}$ in the correction term

$$k_m = \frac{2\pi}{\lambda_m}\left\{1 - \frac{(3n-1)\pi^2 a^2}{n(n^2-1)\lambda_m^2}\right\} \tag{43}$$

and

$$\gamma_m = \frac{4\pi^2 \rho v_o^2 a^3}{n(n^2-1)\lambda_m^2}\left\{1 - \frac{2(3n-1)\pi^2 a^2}{n(n^2-1)\lambda_m^2}\right\} \tag{44}$$

Correcting for changed boundary conditions (see remarks following Eq. (37)),

$$\gamma_m = \frac{4\pi^2 \rho v_o^2 a^3}{n(n^2-1)\lambda_m^2}\left(1 + \frac{\gamma_o - \gamma_m}{2\rho v_o^2 a}\right)\left(1 - \frac{2(3n-1)\pi^2 a^2}{n(n^2-1)\lambda_m^2}\right) \tag{45a}$$

$$= \frac{4\pi^2 \rho v_o^2 a^3}{n(n^2-1)\lambda_m^2}\left\{1 + \frac{2\pi^2 a^2(\lambda_m^2 - \lambda_o^2)}{n(n^2-1)\lambda_m^2 \lambda_o^2}\right\}\left\{1 - \frac{2(3n-1)\pi^2 a^2}{n(n^2-1)\lambda_m^2}\right\} \tag{45b}$$

$$= \frac{4\pi^2}{\lambda_m^2}\left[\frac{\rho v_o^2 a^3}{n^2-1 + \frac{4\pi^2 a^2}{\lambda_m^2}}\right]\frac{J_n\left(\frac{2\pi i a}{\lambda_m}\right)}{\frac{2\pi i a}{\lambda_m} J_n'\left(\frac{2\pi i a}{\lambda_m}\right)}\left\{1 + \frac{2\pi^2 a^2(\lambda_m^2 - \lambda_o^2)}{n(n^2-1)\lambda_m^2 \lambda_o^2}\right\} \tag{45c}$$

these formulations being equivalent to first order.

Corrections for density of air, viscosity, and finite amplitude of vibration developed by Bohr (3) may now be combined with these results giving finally:

$$\gamma_m = \frac{4\pi^2(\rho + \rho_m)v_o^2 a^3}{n(n^2-1)\lambda_m^2}\left\{1 + \frac{2\pi^2 a^2(\lambda_m^2 - \lambda_o^2)}{n(n^2-1)\lambda_m^2\lambda_o^2}\right\}$$

$$\left\{1 - \frac{2(3n-1)\pi^2 a^2}{n(n^2-1)\lambda_m^2}\right\}\left\{1 + \frac{37b^2}{24a^2}\right\}\left\{1 + 2\left(\frac{\eta\lambda_m}{\pi\rho v_o a^2}\right)^{3/2} + 3\left(\frac{\eta\lambda_m}{\pi\rho v_o a^2}\right)^2\right\} \tag{46}$$

Eq. (46) purports to give the surface tension at a point midway between successive crests in the jet from a measurement of the distance between crests. ρ_m is the density of the medium (usually air); η, the viscosity in poises of the solution. It is presumed that the variation in surface tension over one wave length is small in first order compared to the surface tension itself· if this is not true the calculated surface tension may correspond to a position somewhat displaced from a point midway between crests. It should always be possible; however, to choose experimental conditions such that the variation in surface tansion over one wave length will be small in first order.